2016 Massachusetts Science and Technology/Engineering Curriculum Framework

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The full *Massachusetts Science and Technology/Engineering Curriculum Framework* is available online at the Department's website (www.doe.mass.edu/frameworks/current.html). It is also available in separate sections at www.doe.mass.edu/stem. The downloadable files are the same as this printed version. Feedback, comments, or questions are welcome. Please contact the Office of Science, Technology, Engineering, and Mathematics at mathsciencetech@doe.mass.edu.

Commissioner's Foreword

Dear Colleagues,

I am pleased to present to you the *2016 Massachusetts Science and Technology/Engineering (STE) Curriculum Framework*. This *Framework* articulates statewide guidelines for STE learning, teaching, and assessment for the Commonwealth's public schools.

To prepare students for success in college, career, and civic life, the 2016 STE standards emphasize the need for student engagement, relevance, rigor, and coherence in curriculum and instruction. The standards:

- Focus on conceptual understanding and application of concepts.
- Integrate disciplinary core ideas and practices to reflect the discipline of science.
- Present coherent progressions of STE core ideas and practices from pre-K to high school.
- Include each discipline in grade-level standards pre-K to grade 8.
- Contribute to preparation for post-secondary success in college and careers.
- Coordinate with the English Language Arts (ELA) and Mathematics standards.

The 2016 STE standards maintain much of the content of our prior STE standards with updates to reflect changes identified by the field, changes in science and engineering over the past 15 years, and the addition of inquiry and design skills that students need to successfully engage in this discipline in pre-K–12 classrooms, civic life, and post-secondary opportunities. The 2016 STE standards strengthen the often-lauded standards Massachusetts has relied on since 1996.

I would like to thank all of the individuals and groups that provided input, reviewed comments, and suggested edits to the standards, as well as those who contributed to the sections of the *Framework*. This effort included many representatives from across the state. The Department of Early Education and Care (EEC) and the Department of Higher Education (DHE) were key collaborators to ensure a coherent perspective for all students. I am grateful for the dedication and expertise of all the educators, professionals, scholars, and other participants who engaged with the Department in this endeavor.

I believe a strong understanding of science and technology/engineering is critical for every student in the Commonwealth. Every student must understand the world around them and be able to apply analytical and innovative thinking to complex problems they will face in civic and career contexts. This *Framework* provides guidance and resources intended to help educators and professionals prepare students for such success. Thank you for your ongoing support for quality STE education and for your commitment to achievement of such important goals for all students in the Commonwealth.

Sincerely,

Mitchell D. Chester, Ed.D.
Commissioner of Elementary and Secondary Education

Acknowledgments

The 2016 *Massachusetts Science and Technology/Engineering Curriculum Framework* is the result of the contributions of many educators across the state. Because of the broad-based, participatory nature of the revision process, this document cannot reflect all the views of every contributor; instead it reflects a balanced synthesis of their suggestions. The Department of Elementary and Secondary Education wishes to thank all of the groups and individuals that contributed to the development of these standards: the Science and Technology/Engineering Revision Panel; the Next Generation Science Standards (NGSS) Advisory Group; the Mathematics and Science Advisory Council, as well as the Technology/Engineering Advisory Council (later combined into the STEM Advisory Council); the curriculum and standards subgroup of the Governor's STEM Advisory Council; grade-span teacher groups; professional educational associations and organizations; and all of the individual teachers, administrators, scientists, engineers, science education faculty, informal education staff, parents, business and industry representatives, and others who took the time to provide thoughtful comments and input during the development of the STE standards and the *Framework*.

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Next Generation Science Standards (NGSS) Acknowledgement

The 2016 Massachusetts STE standards are an adaptation of the NGSS, and text of some sections of this *Framework* is drawn from NGSS appendices or includes text that has been adapted from NGSS appendices. Massachusetts appreciates the design of the NGSS, the collaborative approach to NGSS development, and the opportunity to draw upon the NGSS and related appendices.

A Vision of Science and Technology/Engineering Education

Science and Technology/Engineering Education for All Students: The Vision

Our world has never been so complex, and scientific and technological reasoning have never been so necessary to make sense of it all. It is self-evident that science, technology, and engineering (STE) are central to the lives of all Massachusetts citizens when they analyze current events, make informed decisions about healthcare, or decide to support public development of community infrastructure. By the end of grade 12, *all* students must have an appreciation for the wonder of science, possess sufficient knowledge of science and engineering to engage in public discussions on related issues, and be careful consumers of scientific and technological information and products in their everyday lives. Students' STE experience should encourage and facilitate engagement in STE to prepare them for the reality that most careers require some scientific or technical preparation, and to increase their interest in and consideration of careers in science, technology, engineering, and mathematics (STEM). All students, regardless of their future education plan and career path, must have an engaging, relevant, rigorous, and coherent pre-K–12 STE education to be prepared for citizenship, continuing education, and careers.

Qualities of Science and Technology/Engineering Education for All Students

Student engagement with science and technology/engineering is a critical emphasis that can only be achieved through quality curriculum and instruction. The standards attend to relevance, rigor, and coherence, each of which has a corresponding implication for curriculum and instruction:

Emphasis in STE Standards	Implication for Curriculum and Instruction
Relevance: Organized around core explanatory ideas that explain the world around us	The goal of teaching focuses on students analyzing and explaining phenomena and experience
Rigor: Central role for science and engineering practices *with* concepts	Inquiry- and design-based learning involves regular engagement with practices to build, use, and apply knowledge
Coherence: Ideas and practices build over time and among disciplines	Teaching involves building a coherent storyline over time and among disciplines

Engagement

Students need regular opportunities to experience the dynamic, interdisciplinary nature of science and technology/engineering. Curriculum and instruction should instill wonder in students about the world around them through engaging and exciting learning experiences. Students should develop a passion about the natural and designed world and model the inquisitive, analytical, and skeptical nature of science. These goals can only be achieved through a rich and varied STE curriculum that includes thoughtful hands-on and minds-on activities, laboratories, investigations, and design challenges. Students take ownership and responsibility in their learning when they have a role in making decisions and reflecting on their learning. Active engagement in learning promotes a "growth mindset" that allows students to feel they can access content and develop skills, and thus succeed in STE. Instruction designed for student engagement is key to achieving this.

Relevance

Students often want to know why they are learning content in the classroom that seems unrelated to the real world. To understand the world around them, and be more interested in learning about it, they must have opportunities to apply their learning to relevant situations and contexts. The STE standards emphasize the application of knowledge and skills that students need to be analytical thinkers and problem solvers for issues that are crucial in today's world. Relevance in curriculum and instruction is also about meeting the needs of diverse learners, including minorities, females, and those on Individualized Education Program, of low socioeconomic status, or otherwise not traditionally represented in science, technology, and engineering.

To focus on relevance, the STE standards emphasize fewer core ideas over lists of discrete knowledge. For example, understanding the function of living systems includes understanding the role of feedback mechanisms. Feedback mechanisms in organisms allow them to remain stable and stay alive by making changes to maintain appropriate internal conditions even as external conditions change. A similar principle applies to ecosystems and to designed systems such as home heating and cooling systems. This focus on interactions in living systems is different from an emphasis on identification of body parts or components of an ecosystem. A focus on core ideas helps students to understand mechanisms and causes underlying a range of phenomena and apply their content understandings to real-world and novel situations (NRC, 2012).

Knowledge alone is not enough: students need to be able to act on that knowledge. Students need to be able to apply science and engineering practices—skills that let them analyze a natural phenomenon or designed system and determine underlying mechanisms and causes—in civic, college, and career contexts. Coupling practice with content gives the context for performance, whereas practices alone are activities and content alone is memorization. Quality STE education must attend to both in order for students to successfully apply their learning to understand and analyze their world.

Rigor

Rigor in STE teaching and learning is achieved by relating conceptual understanding of core ideas (content), science and engineering practices (skills), and application of those to the natural and designed world. Such rigor is how students will be able to apply or transfer their school learning to civic, college, and career contexts. The STE standards are explicitly designed to relate these three aspects in learning outcomes; curriculum and instruction should do so as well.

Coherence

Quality STE education is purposefully designed to support a progression of learning over time. STE education begins early, when children are natural investigators who build and ask questions in many contexts. This should be nurtured through subsequent years. Students should be engaged in developing and applying the science and engineering practices with the core ideas throughout pre-K–12. Every grade's STE education should build on the prior year, support the development of more sophisticated skills, increase the opportunity to relate and use multiple practices at once, and provide more sophisticated concepts and tasks in which to apply the practices. Integration of practices with concepts in purposeful ways throughout pre-K–12 ensures that all students have the opportunity to learn and apply scientific and technical reasoning in a wide array of contexts and situations that they need for postsecondary success. This can only happen if curriculum and instruction is purposefully designed to be coherent across time.

Three Important Goals for All Students: Civic Participation, College Preparation, and Career Readiness

The goal of STE education is to develop scientifically and technologically literate citizens who can solve complex, multidisciplinary problems and apply analytical reasoning and innovative thinking to real-world applications needed for civic participation, college preparation, and career readiness.

Civic Participation

High-quality science and technology/engineering education relates student interests and experiences to real-world problems and decisions. Research demonstrates the importance of embracing diversity as a means of enhancing learning about science and the world, especially as society becomes progressively more diverse (NRC, 2012, p. 29). Leveraging multiple relevant societal contexts from STE including nature, the history of science, cultural and technological perspectives, and community issues, promotes equity, deepens understanding through application, and builds student identity as members of active civic and STE communities.

College Preparation

A quality STE education that integrates concepts and practices is critical to college preparation. The College Board has highlighted the value of science and engineering practices in its work to define college readiness: "In order for a student to be college-ready in science, he or she must…have knowledge of the overarching ideas in the science disciplines (i.e., earth and space science, life science, physical science, and engineering) and how the practices of science are situated within this content…" (College Board, 2010, p. 3). The *Standards for College Success* (College Board, 2009) and redesigned Advanced Placement (AP) science courses (e.g., AP Biology Exam [College Board, 2015]) reflect the need to integrate science practices. College Board expectations focus on understanding, rather than memorization, and on the use of that understanding in the context of practices.

ACT has shown that postsecondary instructors greatly value the use of process or inquiry skills (science and engineering practices)—in fact, that they value these skills equally to fundamental content. ACT notes [*sic*]: "Postsecondary expectations clearly state the process and inquiry skill in science are critical as well as rigorous understanding of fundamental (not advanced) science topics" (ACT, 2011, p. 9). The critical role of practices in preparing students for success in college-level science is further echoed by David Conley in *College Knowledge* (2005). Conley's surveys of higher education faculty identified students' ability to conduct meaningful research and use practices that lead toward quality research as a key college- and career-ready indicator.

The *Admissions Standards for the Massachusetts University System and the University of Massachusetts* (www.mass.edu/forstufam/admissions/admissionsstandards.asp) also emphasize the need to include both concepts and practices. They state that three science courses, incorporating laboratory work, must be completed in order to fulfill the minimum science requirement for admission to the Commonwealth's four-year public institutions. All high school courses based on the standards presented in this document should include substantive laboratory and/or fieldwork (see Appendix VII) to allow all students the opportunity to meet or exceed this requirement.

Career Readiness

Most jobs and postsecondary opportunities that provide a living wage now require an increased amount of scientific and technical proficiency. The skills and background that students learn through their STE education serve as the foundation for solving problems and understanding issues they will encounter in their careers and will provide the intellectual tools needed to develop strategies for dealing with these issues. The use of various forms of modeling and problem solving, both learned through STE practices, applies to an infinite number of career paths, including those that not typically characterized as STE.

For those considering STEM careers, science and engineering practices are also receiving increased attention in the context of STEM career preparation. A strong foundation in K–12 engagement and learning will keep these opportunities open for students to pursue. The redesigned AP science curricula, the American Association for the Advancement of Science (AAAS) publication *Vision and Change* (2011), and the *Scientific Foundations for Future Physicians* (AAMC and HHMI, 2009) identify overlapping science practices as key to postsecondary opportunities.

Students' pre-K–12 STE experience should encourage and facilitate active engagement, relevant contexts, rigorous expectations, and coherence to prepare them for the range of careers that now require some scientific and technical preparation, and to increase students' interest in and consideration of STEM-specific careers.

Massachusetts' Definition of College and Career Readiness

The Massachusetts definition for college and career readiness (www.doe.mass.edu/ccr/) includes subject-specific components that articulate essential learning competencies (for mathematics and English language arts, currently). The essential competencies for STE, developed during the standards revision process with input from many stakeholders, define the STE component:

> Essential Competencies: Learning
>
> Students who are college and career ready in Science and Technology/Engineering will demonstrate the academic knowledge, skills, and practices necessary to enter into and succeed in entry-level, credit-bearing science, engineering or technical courses; certificate or workplace training programs requiring an equivalent level of science; or a comparable entry-level science or technical course at the institution. College and career ready students in Science and Technology/Engineering will be academically prepared to:
>
> - Analyze scientific phenomena and solve technical problems in real-world contexts using relevant science and engineering practices and disciplinary core ideas.
> - Use appropriate scientific and technical reasoning to support, critique, and communicate scientific and technical claims and decisions.
> - Appropriately apply relevant mathematics in scientific and technical contexts.

Summary

A student's ability to engage in scientific and technical reasoning through relevant experience results in better understanding of science and engineering, increased mastery of sophisticated subject matter, a better ability to explain the world, and increased interest in STEM fields. These are key outcomes for successful engagement in civic, college, or career contexts.

Key Features of the STE Standards to Promote the Vision

The science and technology/engineering standards are intended to drive engaging, relevant, rigorous, and coherent instruction that emphasizes student mastery of both disciplinary core ideas (concepts) and application of science and engineering practices (skills) to support student readiness for citizenship, college, and careers. The STE standards embody several key features to support this goal, including a number of features consistent with Massachusetts' mathematics and English language arts (ELA) standards:

1. *The standards focus on conceptual understanding and application of concepts.*
   The standards are focused on a limited set of disciplinary core ideas that build across grades and lead to conceptual understanding and application of concepts. They are written to both articulate the broad concepts *and* key components that specify expected learning. In particular, the disciplinary core ideas emphasize the principles students need to analyze and explain natural phenomena and designed systems they experience in the world.
2. *Integration of disciplinary core ideas and practices reflects the interconnected nature of science and engineering.*
   The standards integrate disciplinary core ideas with scientific and engineering practices. The integration of disciplinary core ideas and practices reflects how science and engineering are applied and practiced every day. It is shown to enhance student learning of both and results in rigorous learning expectations aligned with similar expectations in mathematics and ELA standards.
3. *The standards emphasize preparation for postsecondary success for citizenship, college, and careers.*
   The standards include science and engineering practices necessary to engage in scientific and technical reasoning, a key aspect of civic participation as well as college and career readiness. The standards articulate core ideas and practices students need to succeed in entry-level, credit-bearing science, engineering, or technical courses in college or university; certificate or workplace training programs requiring an equivalent level of science; or comparable entry-level science or technical courses, as well as jobs and postsecondary opportunities that require scientific and technical proficiency to earn a living wage.
4. *STE core ideas and practices progress coherently from pre-K to high school.*
   The standards emphasize a focused and coherent progression of concepts and skills from grade span to grade span, allowing for a dynamic process of knowledge and skill building throughout a student's scientific education. The progression gives students the opportunity to learn more sophisticated material and reconceptualize their understanding of how the natural and designed world work, leading to the scientific and technical understanding and reasoning skills needed for postsecondary success.
5. *Each discipline is included in grade-level standards for pre-K to grade 8.*
   To achieve consistency across schools and districts and to facilitate collaboration, resource sharing, and effective education for transient populations, the pre-K to grade 8 standards are presented by grade level. All four disciplines (earth and space science, life science, physical science, and technology/engineering) are included in each grade to encourage integration across the year and through curriculum. This reflects the nature of science and engineering as experienced in every-day life and allows attention to crosscutting concepts that aid analysis of the world.
6. *The STE standards are coordinated with the Commonwealth's ELA and mathematics standards.*
   The STE standards require the use and application of ELA and mathematics to support STE learning. The three sets of standards overlap in meaningful and substantive ways, particularly in regard to practices that are consistent across all three, and offer an opportunity for all students to better apply and learn STE.

The Massachusetts economy, individual career paths, and civic life are all very dynamic; students' education needs to be too. Quality science and technology/engineering education is needed at all grade levels and should be a key emphasis of every academic program. An encompassing pre-K to high school STE learning experience is essential for students to be prepared for citizenship, college, and careers.

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Guiding Principles for Effective Science and Technology/Engineering Education

Teaching and learning are at the heart of quality science and technology/engineering education. The vision of the Massachusetts STE standards is to engage students in the core ideas through the integration of science and engineering practices, while making connections to what they know and the world they live in. The goal of the Guiding Principles is to help educators create relevant, rigorous, and coherent STE programs that support student engagement, curiosity, analytical thinking, and excitement for learning over time. Educators, administrators, and curriculum designers can refer to the Guiding Principles to develop effective pre-K–12 STE programs. The Guiding Principles are organized to reflect the need for relevance (Principles 1–2), rigor (Principles 3–5), and coherence (Principles 6–9) in STE programs. Strong STE programs effectively support student learning so they are prepared for a dynamic world.

Guiding Principle I (Relevance)

An effective science and technology/engineering program develops students' ability to apply their knowledge and skills to analyze and explain the world around them.

Students are naturally curious and motivated to know more about the world in which they live. Asking questions about everyday phenomena, issues, and how things work can provide rich science learning opportunities for all students. An STE curriculum that is carefully designed around engaging, relevant, real-world interdisciplinary questions increases student motivation, intellectual engagement, and sense making. Learning theory research shows that expert knowledge is developed more effectively through these interdisciplinary real-world connections than through isolated content or practice (e.g., NRC, 2012; Schwartz et al., 2009). Real applications of science—and rapid developments in STE fields such as biotechnology, clean energy, medicine, forensics, agriculture, or robotics—can promote student interest and demonstrate how the core ideas in science are applied in real-world contexts.

An integrated STE curriculum that reflects what we know about the learning of science and how mastery develops over time promotes deeper learning in science (e.g., Wilson et al., 2010). Each domain of science has its particular approach and area of focus. However, students need to understand that much of the scientific and technological work done in the world draws on multiple disciplines. Oceanographers, for instance, use their knowledge of physics, chemistry, biology, earth science, and technology to chart the course of ocean currents. And when a community initiates a public works project, such as removing a combined sewer overflow system, there are various aspects of physics, biology, technology, and chemistry to consider. Connecting the domains of STE with one another and with mathematical study, and to applications in the world, helps students apply, transfer, and adapt their learning to new situations and problems.

Guiding Principle II
(Relevance)

An effective science and technology/engineering program addresses students' prior knowledge and preconceptions.

Students are innately curious about the world and wonder how things work. They may make spontaneous, perceptive observations about natural objects and processes or designed objects and systems, and can often be found taking things apart and reassembling them. In many cases, students have developed mental models about how the world works. These mental models may be inaccurate or incomplete, even though they make sense to the students, and inaccuracies can hinder learning.

Research show that children can hold on to misconceptions even while reproducing what they have been taught are the "correct answers." They may find a variety of ingenious ways to reconcile their misconception with the correct knowledge. Teachers must be skilled at uncovering inaccuracies in students' prior knowledge and observations, and in devising experiences that will challenge inaccurate beliefs and give students compelling reasons and evidence to redirect their learning along more productive routes. Instruction that addresses something students may wonder about or a discrepant event can inspire them to search for evidence and analyze information, to develop a reasonable explanation. Students' natural curiosity provides one entry point for learning experiences designed to address students' preconceptions in STE.

Advancing student learning is not only about "fixing" misconceptions about individual concepts. It is about building and revising networks of concepts so students build interrelated ideas. A key assumption of the standards is that concepts and practices progress over time, becoming more sophisticated and scientific as students revise and reconceptualize their understandings. Recognizing that learners use their experiences and background knowledge to actively construct meaning helps educators effectively accommodate and address student prior knowledge and interests to enhance learning.

Guiding Principle III
(Rigor)

Investigation, experimentation, design, and analytical problem solving are central to an effective science and technology/engineering program.

All students can develop proficiency in STE if instruction provides them with relevant and engaging opportunities. This includes a range of scientific investigations and thinking, including—but not limited to—inquiry and investigation, collection and analysis of evidence, analytical reasoning, and communication and application of information. Investigations introduce students to the nature of original research and design, increase students' understanding of scientific and technological concepts, promote skill development, and provide entry points for all learners. Lessons should be designed so that knowledge and skills are developed and used together on a regular basis.

Research shows that students learn when they have the opportunity to reflect on how the practices contribute to the accumulation of scientific knowledge. This means, for example, that when students carry out an investigation, develop models, articulate questions, or engage in arguments, they have opportunities to think about what they have done and why. Puzzlement and uncertainty are common features in experimentation. Students need time to examine their ideas as they apply them in explaining a natural phenomenon or solving a design problem. Opportunities for students to reflect on their own ideas, collect evidence, make inferences and predictions, and discuss their findings are all crucial to growth in understanding. These opportunities must be carefully chosen to link to important scientific ideas and give students ample time to generate and interpret evidence and develop explanations of the natural world through sustained investigations. It can also offer students an opportunity to monitor and evaluate their work. Through this kind of reflection and active processing, students understand the importance of each practice and develop a nuanced appreciation of the nature of science (also see Appendix VIII).

GUIDING PRINCIPLE IV
(RIGOR)

An effective science and technology/engineering program provides opportunities for students to collaborate in scientific and technological endeavors and communicate their ideas.

Scientists and engineers work as members of their professional communities. Ideas are tested, modified, extended, and reevaluated by those professional communities over time. Thus, the ability to convey ideas to others is essential for these advances to occur. In a classroom, student learning is advanced through social interactions among students, teachers, and external experts. In order to learn how to effectively communicate scientific and technological ideas, students require practice in making written and oral presentations, fielding questions, responding to critiques, and developing replies. Students need opportunities to talk about their work in focused discussions with peers and with those who have more experience and expertise. This communication can occur informally, in the context of an ongoing student collaboration or in an online consultation with a scientist or engineer, or more formally, when a student presents findings from an individual or group investigation. Opportunities to collaborate and communicate are critical to advance students' STE learning.

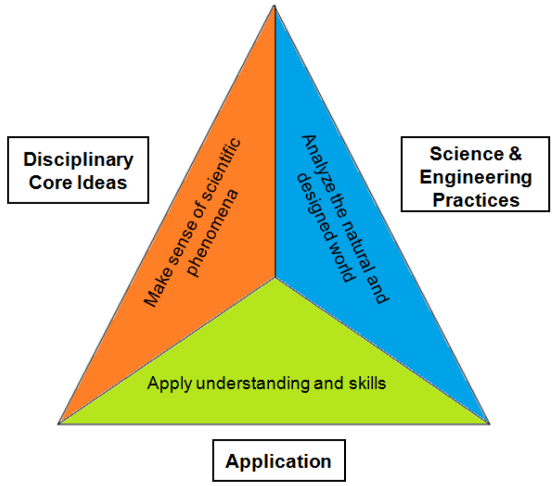
GUIDING PRINCIPLE V
(RIGOR)

An effective science and technology/engineering program conveys high academic expectations for all students.

A high-quality education system simultaneously serves the goals of equity, excellence, and access for all students. At every level of the education system, teachers should act on the belief that young people from every background can learn rigorous STE content and engage in sophisticated analytical practices. Teachers and guidance personnel should advise students and parents that rigorous courses in STE at all grades will prepare them for success in college and the workplace, while elective and advanced courses can help them enter a STEM field, if that is their goal. After-school, weekend, and summer enrichment programs offered by school districts or communities may be especially valuable and should be open to all. Schools and districts should also invite role models from business and the community to visit classes, work with students, and contribute to STE instruction.

Regardless of whether students go on to an institute of higher education or to a workplace, they should be equipped with the skills and habits required for postsecondary success. Skills, such as the ability to work through difficult problems, to be creative in problem solving, and to think critically and analytically, will serve students in any setting.

The STE standards are designed to include three interrelated components necessary for such preparation: conceptual understanding of disciplinary core ideas, science and engineering practices, and application to the natural and designed world. These components are illustrated in this graphic:



When students work toward high expectations in STE, they develop the foundations needed for success after graduation.

GUIDING PRINCIPLE VI (COHERENCE)

An effective science and technology/engineering program integrates STE learning with mathematics and disciplinary literacy.

Mathematics is an essential tool for scientists and engineers because it specifies in precise and abstract (general) terms many attributes of natural phenomena and human-made systems. Mathematics facilitates precise analysis and prediction through formulae that represent the nature of relationships among components of a system (e.g., $F = ma$). Mathematics can also be used to quantify dimensions and scale, allowing investigations of questions such as: How small is a bacterium? How large is a star? How dense is lead? How fast is sound? How hard is a diamond? How sturdy is the bridge? How safe is the plane? With such analyses, all kinds of intellectual and practical questions can be posed, predicted, and solved.

In addition to mathematics, reading, writing, and communication skills are necessary elements of learning and applying STE (also see Guiding Principle IV). Teachers should consistently support students in acquiring comprehension skills and strategies to deepen students' understanding of STE concepts as represented and conveyed in a variety of texts. Scientific and technical texts contain specialized knowledge that is organized in a specific way, including informational text, diagrams, charts, graphs, and formulas. For example, scientific texts will often articulate a general principle that describes a pattern in nature, followed by evidence that supports and illustrates the principle. STE classrooms make use of a variety of text materials, including scientific and technical articles, journals, lab instructions, reports, and textbooks. Texts are generally informational in nature, rather than narrative, and often include technical information related to a particular phenomenon, process, or structure. Students should be able to use a variety of texts to distinguish fact from opinion, make inferences, draw conclusions, and collect evidence to test hypotheses and build arguments. Teachers should help students understand that the types of texts students read, along with the reason(s) for reading these texts, are specific to STE. Supporting the development of students' literacy skills will help them to deepen their understanding of STE concepts.

Successful STE learning requires explicit opportunities to develop mathematics and disciplinary literacy knowledge and skills (also see Appendix II).

GUIDING PRINCIPLE VII (COHERENCE)

An effective science and technology/engineering program uses regular assessment to inform student learning, guide instruction, and evaluate student progress.

> Teaching without attention to learners' perspectives and prior knowledge is like flying a plane in fog without instruments.
>
> Ball & Forzani, 2012

Assessment reflects classroom expectations and shows outcomes of student learning based on established knowledge and performance goals. The learning standards in this *Framework* are a key resource for setting such knowledge and performance objectives in STE. Assessment assists teachers in improving classroom practice, planning curricula, developing self-directed learners, reporting student progress, and evaluating programs. It provides students with feedback about how their knowledge and skills are developing and what can be done to improve them. It lets parents know how well their children are doing and what needs to be done to help them do better.

Diagnostic information gained from different types of assessment enables teachers to adjust their day-to-day and week-to-week practices to foster greater student achievement. There are many types of assessment, such as paper-and-pencil testing, performance assessments, interviews, and portfolios, as well as less formal inventories such as regular observation of student responses to instruction. Given the emphasis on science and engineering practices in the standards, performance-based assessments should be developed that allow students to demonstrate what they have learned in the context of real-world problems and applications.

Learning progressions recognize that learning requires revision of networks of understanding, not revision of individual concepts (or misconceptions) (e.g., Alonzo & Gotwals, 2012; Corcoran et al., 2009; NRC, 2012). If teachers understand where their students are in their understanding of core ideas, and anticipate what students' misconceptions and struggles may be (e.g., Driver et al., 1985, 1994; Keeley et al., 2005; Stanford University, 2012), they can better differentiate instruction and provide scaffolding that allows each student to develop an integrated and deeper understanding of the STE content. It is important to remember that the assessment of the standards should be on understanding the full disciplinary core ideas, not just the pieces in the context of practices.

Guiding Principle VIII
(Coherence)

An effective science and technology/engineering program engages all students, pre-K through grade 12.

Students benefit from studying STE throughout all their years of schooling. Appendix VI discusses the importance of science and engineering in early education. The standards are designed with coherent progressions of learning across time, recognizing that learning requires developing networks of ideas that develop and deepen over time. And the importance of science and engineering practices in the standards highlights the need to coordinate STE experiences over time (also see Appendix VII). Students should learn the fundamental concepts of each domain of STE, as well as the connections across those domains.

A school district or educator can choose from many instructional models and curricular design approaches to effectively engage students in STE learning. One option (among these many) is Project-Based Learning (PBL), in which students go through an extended process of inquiry or design in response to an authentic question, problem, or challenge. They draw from many disciplines when understanding and addressing a complex problem. PBL is centered on student and teacher collaboration and application of academic knowledge and skills. While engaged in PBL, students are engaged in science and engineering practices, as well as cross-disciplinary concepts; students engage in reading and writing informational text and mathematics depending on the driving question of the project. A PBL approach allows for some student choice and voice that promotes motivation and educational equity. PBL includes a process of revision and reflection that requires students to learn how to communicate and receive instructive feedback and to think about their own cognition and understanding.

The amount of time individual students need to achieve STE standards will vary. The chart below provides the time assumed to be provided for STE instruction by grade span to inform the standards development:

Grade Span	Assumed Minutes per Day (Hours per week)
K–2	25 minutes/day (~2 hours/week)
3–5	35 minutes/day (~3 hours/week)
6–8	55 minutes/day (~4.5 hours/week)
9–12	65 minutes/day (~5.5 hours/week)

Schools may take more or less time, depending on local factors that determine curriculum programming within a specific context. STE instruction may be a dedicated time in the school schedule or may be integrated with instruction of other subjects. The goal is for all students to have regular STE instruction every year.

GUIDING PRINCIPLE IX
(COHERENCE)

An effective science and technology/engineering program requires coherent districtwide planning and ongoing support for implementation.

An effective curriculum that addresses the learning standards of this *Framework* must be planned as a cohesive pre-K–12 program. Teachers in different classrooms and at different levels should agree about what is to be taught in given grades. For example, middle school teachers should be able to expect that students coming from different elementary schools within a district share a common set of STE understandings and skills, and that the students they send on to high school will be well prepared for what comes next. In order for this expectation to be met, middle school teachers need to plan curricula in coordination with their elementary and high school colleagues and with district staff.

To facilitate planning, a district coordinator or administrator should be involved in articulating, coordinating, and implementing a districtwide (pre-K–12) STE curriculum. School districts should choose engaging, challenging, and accurate curriculum materials that are based on research into how children learn STE, as well as research about how to address student preconceptions.

When planning for the introduction of a new curriculum, it is important to explicitly identify how success will be measured. Indicators need to be determined and should be communicated to all stakeholders. Supervisors should monitor whether the curriculum is actually being used, how instruction has changed, and how student learning is being realized. Teacher teams, working across grade levels, should look at student work and other forms of assessment to determine whether there is evidence of achievement of the sought-for gains in student understanding.

Implementation of a new curriculum is accomplished over multiple years and requires opportunities for extensive professional development. Teachers must have both content knowledge and pedagogical expertise to use curricular materials in a way that enhances student learning. A well-planned program for professional development provides for both content learning and content-based pedagogical training. It is further recommended that middle and high school courses be taught by teachers who are certified in their areas and who are, therefore, very familiar with the safe use of materials, equipment, and processes.

Finally, students will be more likely to succeed in meeting the standards if they have the curricular and instructional support that encourages their interests in STE. Further, students who are motivated to continue their studies and to persist in more advanced and challenging courses are more likely to become STEM-engaged citizens and, in some cases, pursue careers in STEM fields. These affective goals should be an explicit focus of quality STE programs.

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Science and Technology/Engineering Learning Standards

Overview of the Standards

The Massachusetts standards are an adaptation of the Next Generation Science Standards (NGSS) based on the *Framework for K–12 Science Education* (NRC, 2012). This is done so educators and districts can benefit from commonality across states, including use of NGSS-aligned resources created elsewhere. Common features include:

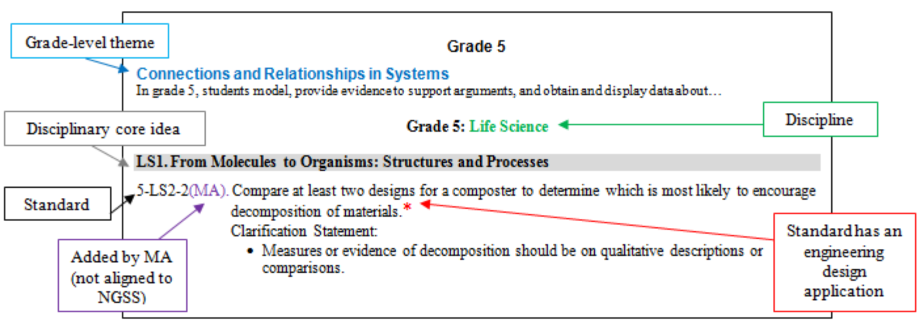
- Integration of science and engineering practices.
- Grade-by-grade standards for elementary school that include all STE disciplines.
- Application of science in engineering contexts.

While the Massachusetts STE standards have much in common with NGSS, public input from across the Commonwealth during the development of the standards identified several needed adaptations for Massachusetts:

- Include technology/engineering as a discipline equivalent to traditional sciences.
- Include only two dimensions (disciplinary core ideas and science and engineering practices) in the standards, while encouraging the inclusion of crosscutting concepts and the nature of science in the curriculum.
- Balance broad concepts with specificity to inform consistent interpretation.
- Maintain the Massachusetts model of introductory high school course options.

Structural Features of the Standards

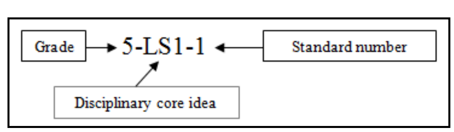
The STE standards are presented using a consistent structure:



The pre-K–8 standards are presented by grade, with each grade focused on a grade-level theme that links the standards and all four STE disciplines (see Appendix V). High school standards are provided for five common introductory-level courses. Standards are organized by disciplinary core ideas, consistently referenced throughout the grades. For standards that are not aligned to NGSS (i.e., standards added by Massachusetts) an "(MA)" has been added to the label. Asterisks (*) designate standards that have an engineering design application.

Labeling/Coding of the Standards

The Massachusetts STE standards are labeled using the NGSS system, as shown here:



The first component of each label indicates the grade (pre-K to grade 8) and/or span (middle or high school). The next component specifies the discipline and core idea. Finally, the number at the end of each label indicates the particular standard within the related set.

Maintaining the labeling system from NGSS is intended to allow Massachusetts' educators access to curriculum and instruction resources developed across the country. This occasionally results in standards that appear to be out of sequence or skip a number (because some NGSS standards are not included in the Massachusetts standards), but the benefits of consistency with NGSS outweigh those of renumbering. *Note that the order in which the standards are listed does not imply or define an intended instructional sequence.*

Components of the Standards

Many standards include *clarification statements* (which supply examples or additional clarification to the standards) and *state assessment boundary statements* (which are meant to specify limits to state assessment). *Note that these are not intended to limit or constrain curriculum or classroom instruction: educators are welcome to teach and assess additional concepts, practices, and vocabulary that are not included in the standards.*

Relationship of Standards to Curriculum and Instruction

The standards are outcomes, or goals, that reflect what a student should know and be able to do. They do not dictate a manner or methods of teaching. The standards are written in a way that expresses the concept and skills to be achieved and demonstrated by students, but leaves curricular and instructional decisions to districts, schools, and teachers. The standards are not a set of instructional activities or assessment tasks. They are statements of what students should be able to do *as a result of* instruction.

In particular, it is important to note that the scientific and engineering practices are not teaching strategies—they are important learning goals in their own right; they are skills to be learned as a result of instruction. As the standards are performances meant to be accomplished at the conclusion of instruction, quality instruction should engage students in multiple practices throughout instruction. Students cannot comprehend scientific practices, or fully appreciate the nature of scientific knowledge itself, without learning the science and engineering practices. This *Framework* uses the term "practices" instead of terms such as "inquiry" or "skills" to emphasize that the practices are outcomes to be learned, not a method of instruction.

It is also important to note that the standards identify the most essential material for students to know and do. They are not an exhaustive list of all that could be included in a student's science education; students should not be prevented from going beyond them where appropriate. Teachers have the flexibility to arrange the standards in any order within a grade level and add areas of study to suit the needs of their students and science programs. Including various applications of science, such as biotechnology, clean energy, medicine, forensics, agriculture, or robotics, would nicely facilitate student interest and demonstrate how the standards are applied in real-world contexts (see Appendix IX).

References

National Research Council (NRC). (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: The National Academies Press.

Use of Selected Terms

This section clarifies the intended use of certain terms in the standards.

Engineering Design

- *Design problem:* An articulation of a problem to be solved or a thing to be improved that addresses a personal, communal, or societal need. Engaging in or addressing a design problem results in a product (a physical thing or a process).

Scale

- *Local:* Describes an area relevant to what is being studied, generally a local community or small region (e.g., an area of a state). Does not have to be near where the student lives, although that can be the area under study. A local area can also be, for example, a place in Costa Rica if the topic of study is a rain forest, or a place in the Arctic if that is being studied.
- *Regional:* Generally refers to a statewide or multistate perspective relative to what is being studied or, if on another continent, approximately a country or small set of countries that constitute a regional scope.

Material Properties

Different properties of materials are specified and used throughout the standards. The table below shows the grade span at which each property is introduced. Once introduced at one grade level, the property may be used, referred to, or expected in any later grade. A check mark (✓) indicates that the property is specified again in the later grade span.

Pre-K–2	3–5	6–8	HS
Absorbency			
Color	✓	✓	
Flexibility		✓	
Hardness	✓	✓	✓
Texture			
	Electrical conductivity	✓	
	Response to magnetic forces		
	Reflectivity		
	Solubility	✓	✓
	Thermal conductivity	✓	✓
		Boiling point	✓
		Density	✓
		Ductility	
		Flammability	
		Melting point	✓
			Elasticity
			Plasticity
			Reactivity
			Resistance to force
			Surface tension
			Vapor pressure

Grades Pre-K–2: Overview of Science and Engineering Practices

The development of science and engineering practices begins very early, even as babies and young children inquire about and explore how the world works. Formal education should advance students' development of the skills necessary to engage in scientific inquiry and engineering design. These are the skills that provide the foundation for the scientific and technical reasoning that is so critical to success in civic life, postsecondary education, and careers. Inclusion of science and engineering practices in standards only speaks to the types of performances students should be able to demonstrate at the end of instruction at a particular grade; the standards do not limit what educators and students should or can be engaged in through a well-rounded curriculum.

Pre-K through grade 2 standards integrate all eight science and engineering practices. Pre-K standards ask students to demonstrate an ability to ask questions, set up simple investigations, analyze evidence, observations, and data for patterns, and use evidence to explain or develop ideas about how phenomena work. Kindergarten standards call for students to show further development of investigation and communication skills, as well as application of science concepts to designing solutions to problems, and to now use information obtained from text and media sources. Grade 1 standards call for students to continue developing investigation skills, including their ability to pose scientific questions as well as their ability to analyze observations and data and to effectively use informational sources. Grade 1 standards also call for students to demonstrate their ability to craft scientific explanations using evidence from a variety of sources. Grade 2 standards call for students to use models in a scientific context and further their skills in a number of the practices, including investigations, data analysis, designing solutions, argumentation, and use of informational sources.

Some examples of specific skills students should develop in these grades:

1. Raise questions about how different types of environments provide homes for living things; ask and/or identify questions that can be answered by an investigation.
2. Use a model to compare how plants and animals depend on their surroundings; develop and/or use a model to represent amounts, relationships, and/or patterns in the natural world; distinguish between a model and the actual object and/or process the model represents.
3. Conduct an investigation of light and shadows; plan and conduct an investigation collaboratively to produce data to answer a question; make observations and/or relative measurements to collect data that can be used to make comparisons.
4. Analyze data to identify relationships among seasonal patterns of change; use observations to describe patterns and/or relationships in the natural world and to answer scientific questions.
5. Decide when to use qualitative vs. quantitative information; use counting and numbers to describe patterns in the natural world.
6. Use information from observations to construct an evidence-based account of nature.
7. Construct an argument with evidence for how plants and animals can change the environment; distinguish between opinions and evidence in one's own explanations; listen actively to others to indicate agreement or disagreement based on evidence.

8. Obtain information to compare ways that parents and their offspring behave to survive; obtain information using various texts, text features, or other media to answer a question.

While presented as distinct skill sets, the eight practices intentionally overlap and interconnect. Skills such as those outlined above should be reflected in curricula and instruction that engage students in an integrated use of the practices. See the Science and Engineering Practices Progression Matrix (Appendix I) for more information, including particular skills for students in grades pre-K–2.

Pre-Kindergarten

The World Around Me

Pre-K students focus on experiencing and making observations of the world around them. They are beginning to learn about their own environment as they observe plants and animals, the Moon and the Sun, and the daily weather. They experience their world through their senses and body parts and begin to recognize that animals also use their senses and body parts to meet their basic needs. They investigate pitch and volume, shadow and light, liquids and solids, and how things move. They sort materials by simple observable properties such as texture and color. They share their understanding of these concepts through discussion as they develop their language and quantitative skills. Pre-K students build awareness of the wide variety of natural phenomena and processes in the world around them.

Pre-K: Earth and Space Sciences

ESS1. Earth's Place in the Universe

PreK-ESS1-1(MA). Demonstrate awareness that the Moon can be seen in the daytime and at night, and of the different apparent shapes of the Moon over a month.

Clarification Statement:

- The names of moon phases or sequencing of moon phases is not expected.

PreK-ESS1-2(MA). Observe and use evidence to describe that the Sun is in different places in the sky during the day.

ESS2. Earth's Systems

PreK-ESS2-1(MA). Raise questions and engage in discussions about how different types of local environments (including water) provide homes for different kinds of living things.

PreK-ESS2-2(MA). Observe and classify non-living materials, natural and human made, in the local environment.

PreK-ESS2-3(MA). Explore and describe different places water is found in the local environment.

PreK-ESS2-4(MA). Use simple instruments to collect and record data on elements of daily weather, including sun or clouds, wind, snow or rain, and higher or lower temperature.

PreK-ESS2-5(MA). Describe how local weather changes from day to day and over the seasons and recognize patterns in those changes.

Clarification Statement:

- Descriptions of the weather can include sunny, cloudy, rainy, warm, windy, and snowy.

PreK-ESS2-6(MA). Provide examples of the impact of weather on living things.

Clarification Statement:

- Make connections between the weather and what they wear and can do and the weather and the needs of plants and animals for water and shelter.

ESS3. Earth and Human Activity

PreK-ESS3-1(MA). Engage in discussion and raise questions using examples about local resources (including soil and water) humans use to meet their needs.

PreK-ESS3-2(MA). Observe and discuss the impact of people's activities on the local environment.

Pre-K: Life Science

LS1. From Molecules to Organisms: Structures and Processes

PreK-LS1-1(MA). Compare, using descriptions and drawings, the external body parts of animals (including humans) and plants and explain functions of some of the observable body parts.

Clarification Statement:

- Examples can include comparison of humans and horses: humans have two legs and horses four, but both use legs to move.

PreK-LS1-2(MA). Explain that most animals have five senses they use to gather information about the world around them.

PreK-LS1-3(MA). Use their five senses in their exploration and play to gather information.

LS2. Ecosystems: Interactions, Energy, and Dynamics

PreK-LS2-1(MA). Use evidence from animals and plants to define several characteristics of living things that distinguish them from non-living things.

PreK-LS2-2(MA). Using evidence from the local environment, explain how familiar plants and animals meet their needs where they live.

Clarification Statements:

- Basic needs include water, food, air, shelter, and, for most plants, light.
- Examples of evidence can include squirrels gathering nuts for the winter and plants growing in the presence of sun and water.
- The local environment includes the area around the student's school, home, or adjacent community.

PreK-LS2-3(MA). Give examples from the local environment of how animals and plants are dependent on one another to meet their basic needs.

LS3. Variation of Traits

PreK-LS3-1(MA). Use observations to explain that young plants and animals are like but not exactly like their parents.

Clarification Statement:

- Examples of observations include puppies that look similar but not exactly the same as their parents.

PreK-LS3-2(MA). Use observations to recognize differences and similarities among themselves and their friends.

Pre-K: Physical Sciences

PS1. Matter and Its Interactions

PreK-PS1-1(MA). Raise questions and investigate the differences between liquids and solids and develop awareness that a liquid can become a solid and vice versa.

PreK-PS1-2(MA). Investigate natural and human-made objects to describe, compare, sort, and classify objects based on observable physical characteristics, uses, and whether something is manufactured or occurs in nature.

PreK-PS1-3(MA). Differentiate between the properties of an object and those of the material of which it is made.

PreK-PS1-4(MA). Recognize through investigation that physical objects and materials can change under different circumstances.

Clarification Statement:

- Changes include building up or breaking apart, mixing, dissolving, and changing state.

PS2. Motion and Stability: Forces and Interactions

PreK-PS2-1(MA). Using evidence, discuss ideas about what is making something move the way it does and how some movements can be controlled.

PreK-PS2-2(MA). Through experience, develop awareness of factors that influence whether things stand or fall.

Clarification Statement:

- Examples of factors in children's construction play include using a broad foundation when building, considering the strength of materials, and using balanced weight distribution in a block building.

PS4. Waves and Their Applications in Technologies for Information Transfer

PreK-PS4-1(MA). Investigate sounds made by different objects and materials and discuss explanations about what is causing the sounds. Through play and investigations, identify ways to manipulate different objects and materials that make sound to change volume and pitch.

PreK-PS4-2(MA). Connect daily experiences and investigations to demonstrate the relationships between the size and shape of shadows, the objects creating the shadow, and the light source.

Kindergarten

Reasons for Change

In kindergarten, students build on early experiences observing the world around them as they continue to make observations that are more quantitative in nature and help them identify why some changes occur. Students begin to learn to use these observations as evidence to support a claim through growing language skills. They learn that all animals and plants need food, water, and air to grow and thrive and that the fundamental difference between plants and animals is a plant's ability to make its own food. Students build their quantitative knowledge of temperature in relation to the weather and its effect on different kinds of materials. They observe that the amount of sunlight shining on a surface causes a temperature change and they design a structure to reduce the warming effects of sunlight. They investigate motions of objects by changing the strength and direction of pushes and pulls. They provide examples of plants and animals that can change their environment through their interactions with it. In kindergarten science, students begin to identify reasons for changes in some common phenomena.

Kindergarten: Earth and Space Sciences

ESS2. Earth's Systems

K-ESS2-1. Use and share quantitative observations of local weather conditions to describe patterns over time.

Clarification Statements:

- Examples of quantitative observations could include numbers of sunny, windy, and rainy days in a month, and relative temperature.
- Quantitative observations should be limited to whole numbers.

K-ESS2-2. Construct an argument supported by evidence for how plants and animals (including humans) can change the environment.

Clarification Statement:

- Examples of plants and animals changing their environment could include a squirrel digging holes in the ground and tree roots that break concrete.

ESS3. Earth and Human Activity

K-ESS3-2. Obtain and use information about weather forecasting to prepare for, and respond to, different types of local weather.

K-ESS3-3. Communicate solutions to reduce the amount of natural resources an individual uses.*

Clarification Statement:

- Examples of solutions could include reusing paper to reduce the number of trees cut down and recycling cans and bottles to reduce the amount of plastic or metal used.

[K-ESS3-1 from NGSS is not included.]

Kindergarten: Life Science

LS1. From Molecules to Organisms: Structures and Processes

K-LS1-1. Observe and communicate that animals (including humans) and plants need food, water, and air to survive. Animals get food from plants or other animals. Plants make their own food and need light to live and grow.

K-LS1-2(MA). Recognize that all plants and animals grow and change over time.

Kindergarten: Physical Science

PS1. Matter and Its Interactions

K-PS1-1(MA). Investigate and communicate the idea that different kinds of materials can be solid or liquid depending on temperature.

Clarification Statements:

- Materials chosen must exhibit solid and liquid states in a reasonable temperature range for kindergarten students (e.g., 0–80°F), such as water, crayons, or glue sticks.
- Only a qualitative description of temperature, such as hot, warm, and cool, is expected.

PS2. Motion and Stability: Forces and interactions

K-PS2-1. Compare the effects of different strengths or different directions of pushes and pulls on the motion of an object.

Clarification Statements:

- Examples of pushes or pulls could include a string attached to an object being pulled, a person pushing an object, a person stopping a rolling ball, and two objects colliding and pushing on each other.
- Comparisons should be on different relative strengths or different directions, not both at the same time.
- Non-contact pushes or pulls such as those produced by magnets are not expected.

[K-PS2-2 from NGSS is not included.]

PS3. Energy

K-PS3-1. Make observations to determine that sunlight warms materials on Earth's surface.

Clarification Statements:

- Examples of materials on Earth's surface could include sand, soil, rocks, and water.
- Measures of temperature should be limited to relative measures such as warmer/cooler.

K-PS3-2. Use tools and materials to design and build a model of a structure that will reduce the warming effect of sunlight on an area.*

Grade 1

Describing Patterns

In grade 1, students have more fluency with language, number sense, and inquiry skills. This allows them to describe patterns of motion between the Sun, Moon, and stars in relation to the Earth. From this understanding they can identify seasonal patterns from sunrise and sunset data that will allow them to predict future patterns. Building from their experiences in pre-K and kindergarten observing and describing daily weather, they can now examine seasonal data on temperature and rainfall to describe patterns over time. Grade 1 students investigate sound and light through various materials. They describe patterns in how light passes through and sounds differ from different types of materials and use this to design and build a device to send a signal. Students compare the ways different animals and plants use their body parts and senses to do the things they need to do to grow and survive, including typical ways parents keep their young safe so they will survive to adulthood. They notice that though there are differences between plants or animals of the same type, the similarities of behavior and appearance are what allow us to identify them as belonging to a group. Grade 1 students begin to understand the power of patterns to predict future events in the natural and designed world.

Grade 1: Earth and Space Sciences

ESS1. Earth's Place in the Universe

1-ESS1-1. Use observations of the Sun, Moon, and stars to describe that each appears to rise in one part of the sky, appears to move across the sky, and appears to set.

1-ESS1-2. Analyze provided data to identify relationships among seasonal patterns of change, including relative sunrise and sunset time changes, seasonal temperature and rainfall or snowfall patterns, and seasonal changes to the environment.

Clarification Statement:

- Examples of seasonal changes to the environment can include foliage changes, bird migration, and differences in amount of insect activity.

Grade 1: Life Science

LS1. From Molecules to Organisms: Structures and Processes

1-LS1-1. Use evidence to explain that (a) different animals use their body parts and senses 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, and (b) plants have roots, stems, leaves, flowers, and fruits that are used to take in water, air, and other nutrients, and produce food for the plant.

Clarification Statement:

- Descriptions are not expected to include mechanisms such as the process of photosynthesis.

1-LS1-2. Obtain information to compare ways in which the behavior of different animal parents and their offspring help the offspring to survive.

Clarification Statement:

- Examples of behaviors could include the signals that offspring make (such as crying, cheeping, and other vocalizations) and the responses of the parents (such as feeding, comforting, and protecting the offspring).

LS3. Heredity: Inheritance and Variation of Traits

1-LS3-1. Use information from observations (first-hand and from media) to identify similarities and differences among individual plants or animals of the same kind.

Clarification Statements:

- Examples of observations could include that leaves from the same kind of plant are the same shape but can differ in size.
- Inheritance, animals that undergo metamorphosis, or hybrids are not expected.

Grade 1: Physical Science

PS4. Waves and Their Applications in Technologies for Information Transfer

1-PS4-1. Demonstrate that vibrating materials can make sound and that sound can make materials vibrate.

Clarification Statements:

- Examples of vibrating materials that make sound could include tuning forks, a stretched string or rubber band, and a drum head.
- Examples of how sound can make materials vibrate could include holding a piece of paper near a speaker making sound and holding an object near a vibrating tuning fork.

1-PS4-3. Conduct an investigation to determine the effect of placing materials that allow light to pass through them, allow only some light through them, block all the light, or redirect light when put in the path of a beam of light.

Clarification Statements:

- Effects can include some or all light passing through, creation of a shadow, and redirecting light.
- Quantitative measures are not expected.

1-PS4-4. Use tools and materials to design and build a device that uses light or sound to send a signal over a distance.*

Clarification Statements:

- Examples of devices could include a light source to send signals, paper cup and string "telephones," and a pattern of drum beats.
- Technological details for how communication devices work are not expected.

[1-PS4-2 from NGSS is not included.]

Grade 1: Technology/Engineering

ETS1. Engineering Design

1.K-2-ETS1-1. Ask questions, make observations, and gather information about a situation people want to change that can be solved by developing or improving an object or tool.*

1.K-2-ETS1-2. Generate multiple solutions to a design problem and make a drawing (plan) to represent one or more of the solutions.*

[K-2-ETS1-3 is found in grade 2.]

Grade 2

Wholes and Parts

As students grow in their ability to speak, read, write, and reason mathematically, they also grow in their ability to grapple with larger systems and the parts that make them up. In grade 2, students start to look beyond the structures of individual plants and animals to looking at the environment in which the plants and animals live as a provider of the food, water, and shelter that the organisms need. They learn that water is found everywhere on Earth and takes different forms and shapes. They map landforms and bodies of water and observe that flowing water and wind shapes these landforms. Grade 2 students use their observation skills gained in earlier grades to classify materials based on similar properties and functions. They gain experience testing different materials to collect and then analyze data for the purpose of determining which materials are the best for a specific function. They construct large objects from smaller pieces and, conversely, learn that when materials are cut into the smallest possible pieces, they still exist as the same material that has weight. These investigations of how parts relate to the whole provide a key basis for understanding systems in later grades.

Grade 2: Earth and Space Sciences

ESS1. Earth's Place in the Universe

[2-ESS1-1 from NGSS is not included.]

ESS2. Earth's Systems

2-ESS2-1. Investigate and compare the effectiveness of multiple solutions designed to slow or prevent wind or water from changing the shape of the land.*

Clarification Statements:

- Solutions to be compared could include different designs of dikes and windbreaks to hold back wind and water, and different designs for using shrubs, grass, and trees to hold back the land.
- Solutions can be generated or provided.

2-ESS2-2. Map the shapes and types of landforms and bodies of water in an area.

Clarification Statements:

- Examples of types of landforms can include hills, valleys, river banks, and dunes.
- Examples of water bodies can include streams, ponds, bays, and rivers.
- Quantitative scaling in models or contour mapping is not expected.

2-ESS2-3. Use examples obtained from informational sources to explain that water is found in the ocean, rivers and streams, lakes and ponds, and may be solid or liquid.

2-ESS2-4(MA). Observe how blowing wind and flowing water can move Earth materials from one place to another and change the shape of a landform.

Clarification Statement:

- Examples of types of landforms can include hills, valleys, river banks, and dunes.

Grade 2: Life Science

LS2. Ecosystems: Interactions, Energy, and Dynamics

2-LS2-3(MA). Develop and use models to compare how plants and animals depend on their surroundings and other living things to meet their needs in the places they live.

Clarification Statement:

- Animals need food, water, air, shelter, and favorable temperature; plants need sufficient light, water, minerals, favorable temperature, and animals or other mechanisms to disperse seeds.

[2-LS2-1 is included in other standards, including K-LS1-1 and 2-LS2-3(MA). 2-LS2-2 from NGSS is not included.]

LS4. Biological Evolution: Unity and Diversity

2-LS4-1. Use texts, media, or local environments to observe and compare (a) different kinds of living things in an area, and (b) differences in the kinds of living things living in different types of areas.

Clarification Statements:

- Examples of areas to compare can include temperate forest, desert, tropical rain forest, grassland, arctic, and aquatic.
- Specific animal and plant names in specific areas are not expected.

Grade 2: Physical Science

PS1. Matter and Its Interactions

2-PS1-1. Describe and classify different kinds of materials by observable properties of color, flexibility, hardness, texture, and absorbency.

2-PS1-2. Test different materials and analyze the data obtained to determine which materials have the properties that are best suited for an intended purpose.*

Clarification Statements:

- Examples of properties could include, color, flexibility, hardness, texture, and absorbency.
- Data should focus on qualitative and relative observations.

2-PS1-3. Analyze a variety of evidence to conclude that when a chunk of material is cut or broken into pieces, each piece is still the same material and, however small each piece is, has weight. Show that the material properties of a small set of pieces do not change when the pieces are used to build larger objects.

Clarification Statements:

- Materials should be pure substances or microscopic mixtures that appear contiguous at observable scales.
- Examples of pieces could include blocks, building bricks, and other assorted small objects.

2-PS1-4. Construct an argument with evidence that some changes to materials caused by heating or cooling can be reversed and some cannot.

Clarification Statements:

- Examples of reversible changes could include materials such as water and butter at different temperatures.
- Examples of irreversible changes could include cooking an egg, freezing a plant leaf, and burning paper.

PS3. Energy

2-PS3-1(MA). Design and conduct an experiment to show the effects of friction on the relative temperature and speed of objects that rub against each other.

Clarification Statements:

- Examples could include an object sliding on rough vs. smooth surfaces.
- Observations of temperature and speed should be qualitative.

Grade 2: Technology/Engineering

ETS1. Engineering Design

2.K-2-ETS1-3. Analyze data from tests of two objects designed to solve the same design problem to compare the strengths and weaknesses of how each object performs.*

Clarification Statements:

- Data can include observations and be either qualitative or quantitative.
- Examples can include how different objects insulate cold water or how different types of grocery bags perform.

[K-2-ETS1-1 and K-2-ETS1-2 are found in grade 1.]

Grades 3–5: Overview of Science and Engineering Practices

Upper elementary is a critical time to engage students in the science and engineering practices. Students form key identities with, or against, science and engineering as they leave elementary school that can shape their relationship to science in later education, and even postsecondary and career choices later in life. Students must be given opportunities to develop the skills necessary for a meaningful progression of development in order to engage in the scientific and technical reasoning so critical to success in civic life, postsecondary education, and careers. Inclusion of science and engineering practices in standards only speaks to the types of performance students should be able to demonstrate at the end of instruction at a particular grade; the standards do not limit what educators and students should or can be engaged in through a well-rounded curriculum.

Standards for grades 3 through 5 integrate all eight science and engineering practices. Some examples of specific skills students should develop in these grades include:

1. Ask questions and predict outcomes about the changes in energy when objects collide; distinguish between scientific (testable) and non-scientific (non-testable) questions; define a simple design problem, including criteria for success and constraints on materials or time.
2. Use graphical representations to show differences in organisms' life cycles; develop a model of a wave to communicate wave features; use a particulate model of matter to explain phase changes; identify limitations of models; use a model to test cause and effect relationships.
3. Conduct an investigation to determine the nature of forces between magnets; make observations and collect data about the effects of mechanical weathering; conduct an experiment on mixing of substances; evaluate appropriate methods for collecting data; make predictions about what would happen if a variable changes.
4. Use graphs and tables of weather data to describe and predict typical weather during a season; analyze and interpret maps of Earth's physical features; use data to evaluate and refine design solutions.
5. Graph and describe the amounts and percentages of fresh and salt water in various reservoirs; measure and graph weights of substances before and after a chemical reaction.
6. Use evidence to explain how variations among individuals can provide advantages in survival and reproduction; provide evidence to explain the effect of multiple forces on the motion of an object; test and refine a simple system designed to filter impurities out of water.
7. Construct an argument that animals and plants have internal and external structures that support their survival, growth, behavior, and reproduction; distinguish among facts, reasoned judgment based on data, and speculation in an argument.
8. Obtain and summarize information about the climate of different regions; gather information on possible solutions to a given design problem; obtain information about renewable and nonrenewable energy sources.

While presented as distinct skill sets, the eight practices intentionally overlap and interconnect. Skills such as those outlined above should be reflected in curricula and instruction that engage students in an integrated use of the practices. See the Science and Engineering Practices Progression Matrix (Appendix I) for more information, including particular skills for students in grades 3–5.

Grade 3

Human Interactions

In grade 3, students develop and sharpen their skills at obtaining, recording and charting, and analyzing data in order to study their environment. They use these practices to study the interactions between humans and earth systems, humans and the environment, and humans and the designed world. They learn that these entities not only interact but influence behaviors, reactions, and traits of organisms. Grade 3 students analyze weather patterns and consider humans' influence and opportunity to impact weather-related events. In life science they study the interactions between and influence of the environment and human traits and characteristics. They use the engineering design process to identify a problem and design solutions that enhance humans' interactions with their surroundings and to meet their needs. Students consider the interactions and consequent reactions between objects and forces, including forces that are balanced or not. Students reason and provide evidence to support arguments for the influence of humans on nature and nature on human experience.

Grade 3: Earth and Space Sciences

ESS2. Earth's Systems

3-ESS2-1. Use graphs and tables of local weather data to describe and predict typical weather during a particular season in an area.

Clarification Statements:

- Examples of weather data could include temperature, amount and type of precipitation (e.g., rain, snow), wind direction, and wind speed.
- Graphical displays should focus on pictographs and bar graphs.

3-ESS2-2. Obtain and summarize information about the climate of different regions of the world to illustrate that typical weather conditions over a year vary by region.

Clarification Statement:

- Examples of information can include climate data (average temperature, average precipitation, average wind speed) or comparative descriptions of seasonal weather for different regions.

State Assessment Boundary:

- An understanding of climate change is not expected in state assessment.

ESS3. Earth and Human Activity

3-ESS3-1. Evaluate the merit of a design solution that reduces the damage caused by weather.*

Clarification Statement:

- Examples of design solutions to reduce weather-related damage could include a barrier to prevent flooding, a wind-resistant roof, and a lightning rod.

Grade 3: Life Science

LS1. From Molecules to Organisms: Structures and Processes

3-LS1-1. Use simple graphical representations to show that different types of organisms have unique and diverse life cycles. Describe that all organisms have birth, growth, reproduction, and death in common but there are a variety of ways in which these happen.

Clarification Statements:

- Examples can include different ways plants and animals begin (e.g., sprout from a seed, born from an egg), grow (e.g., increase in size and weight, produce a new part), reproduce (e.g., develop seeds, root runners, mate and lay eggs that hatch), and die (e.g., length of life).
- Plant life cycles should focus on those of flowering plants.
- Describing variation in organism life cycles should focus on comparisons of the general stages of each, not specifics.

State Assessment Boundary:

- Detailed descriptions of any one organism's cycle, the differences of "complete metamorphosis" and "incomplete metamorphosis," or details of human reproduction are not expected in state assessment.

LS2. Ecosystems: Interactions, Energy, and Dynamics

[3-LS2-1 from NGSS is not included.]

LS3. Heredity: Inheritance and Variation of Traits

3-LS3-1. Provide evidence, including through the analysis of data, that plants and animals have traits inherited from parents and that variation of these traits exist in a group of similar organisms.

Clarification Statements:

- Examples of inherited traits that vary can include the color of fur, shape of leaves, length of legs, and size of flowers.
- Focus should be on non-human examples.

State Assessment Boundary:

- Genetic mechanisms of inheritance or prediction of traits are not expected in state assessment.

3-LS3-2. Distinguish between inherited characteristics and those characteristics that result from a direct interaction with the environment. Give examples of characteristics of living organisms that are influenced by both inheritance and the environment.

Clarification Statements:

- Examples of the environment affecting a characteristic could include normally tall plants stunted because they were grown with insufficient water or light, a lizard missing a tail due to a predator, and a pet dog becoming overweight because it is given too much food and little exercise.
- Focus should be on non-human examples.

LS4. Biological Evolution: Unity and Diversity

3-LS4-1. Use fossils to describe types of organisms and their environments that existed long ago and compare those to living organisms and their environments. Recognize that most kinds of plants and animals that once lived on Earth are no longer found anywhere.

Clarification Statement:

- Comparisons should focus on physical or observable features.

State Assessment Boundary:

- Identification of specific fossils or specific present-day plants and animals, dynamic processes, or genetics are not expected in state assessment.

3-LS4-2. Use evidence to construct an explanation for how the variations in characteristics among individuals within the same species may provide advantages to these individuals in their survival and reproduction.

Clarification Statements:

- Examples can include rose bushes of the same species, one with slightly longer thorns than the other which may prevent its predation by deer, and color variation within a species that may provide advantages so one organism may be more likely to survive and therefore more likely to produce offspring.
- Examples of evidence could include needs and characteristics of the organisms and habitats involved.

3-LS4-3. Construct an argument with evidence that in a particular environment some organisms can survive well, some survive less well, and some cannot survive.

Clarification Statement:

- Examples of evidence could include needs and characteristics of the different organisms (species) and habitats involved.

3-LS4-4. Analyze and interpret given data about changes in a habitat and describe how the changes may affect the ability of organisms that live in that habitat to survive and reproduce.

Clarification Statements:

- Changes should include changes to landforms, distribution of water, climate, and availability of resources.
- Changes in the habitat could range in time from a season to a decade.
- While it is understood that ecological changes are complex, the focus should be on a single change to the habitat.

3-LS4-5(MA). Provide evidence to support a claim that the survival of a population is dependent upon reproduction.

State Assessment Boundary:

- Details of reproduction are not expected in state assessment.

Grade 3: Physical Science

PS2. Motion and Stability: Forces and Interactions

3-PS2-1. Provide evidence to explain the effect of multiple forces, including friction, on an object. Include balanced forces that do not change the motion of the object and unbalanced forces that do change the motion of the object.

Clarification Statements:

- Descriptions of force magnitude should be qualitative and relative.
- Force due to gravity is appropriate but only as a force that pulls objects down.

State Assessment Boundaries:

- Quantitative force magnitude is not expected in state assessment.
- State assessment will be limited to one variable at a time: number, size, or direction of forces.

3-PS2-3. Conduct an investigation to determine the nature of the forces between two magnets based on their orientations and distance relative to each other.

Clarification Statement:

- Focus should be on forces produced by magnetic objects that are easily manipulated.

3-PS2-4. Define a simple design problem that can be solved by using interactions between magnets.*

Clarification Statement:

- Examples of problems could include constructing a latch to keep a door shut and creating a device to keep two moving objects from touching each other.

[3-PS2-2 from NGSS is not included.]

Grade 3: Technology/Engineering

ETS1. Engineering Design

3.3-5-ETS1-1. Define a simple design problem that reflects a need or a want. Include criteria for success and constraints on materials, time, or cost that a potential solution must meet.*

3.3-5-ETS1-2. Generate several possible solutions to a given design problem. Compare each solution based on how well each is likely to meet the criteria and constraints of the design problem.*

Clarification Statement:

- Examples of design problems can include adapting a switch on a toy for children who have a motor coordination disability, designing a way to clear or collect debris or trash from a storm drain, or creating safe moveable playground equipment for a new recess game.

3.3-5-ETS1-4(MA). Gather information using various informational resources on possible solutions to a design problem. Present different representations of a design solution.*

Clarification Statements:

- Examples of informational resources can include books, videos, and websites.
- Examples of representations can include graphic organizers, sketches, models, and prototypes.

[3-5-ETS1-3 and 3-5-ETS1-5(MA) are found in grade 4.]

Grade 4

Matter and Energy

In grade 4, students observe and interpret patterns related to the transfer of matter and energy on Earth, in physical interactions, and in organisms. Students learn about energy—its motion, transfer, and conversion—in different physical contexts. Grade 4 students interpret patterns of change over time as related to the deposition and erosion in landscape formation. They study today's landscapes to provide evidence for past processes. Students learn that animals' internal and external structures support life, growth, behavior, and reproduction. They work through the engineering design process, focusing on developing solutions by building, testing, and redesigning prototypes to fit a specific purpose. Each domain relates to the use of matter and energy over time and for specific purposes.

Grade 4: Earth and Space Sciences

ESS1. Earth's Place in the Universe

4-ESS1-1. Use evidence from a given landscape that includes simple landforms and rock layers to support a claim about the role of erosion or deposition in the formation of the landscape over long periods of time.

Clarification Statements:

- Examples of evidence and claims could include rock layers with shell fossils above rock layers with plant fossils and no shells, indicating a change from deposition on land to deposition in water over time; and a canyon with rock layers in the walls and a river in the bottom, indicating that a river eroded the rock over time.
- Examples of simple landforms can include valleys, hills, mountains, plains, and canyons.
- Focus should be on relative time.

State Assessment Boundary:

- Specific details of the mechanisms of rock formation or specific rock formations and layers are not expected in state assessment.

ESS2. Earth's Systems

4-ESS2-1. Make observations and collect data to provide evidence that rocks, soils, and sediments are broken into smaller pieces through mechanical weathering and moved around through erosion.

Clarification Statements:

- Mechanical weathering processes can include frost wedging, abrasion, and tree root wedging.
- Erosion can include movement by blowing wind, flowing water, and moving ice.

State Assessment Boundary:

- Chemical processes are not expected in state assessment.

4-ESS2-2. Analyze and interpret maps of Earth's mountain ranges, deep ocean trenches, volcanoes, and earthquake epicenters to describe patterns of these features and their locations relative to boundaries between continents and oceans.

ESS3. Earth and Human Activity

4-ESS3-1. Obtain information to describe that energy and fuels humans use are derived from natural resources and that some energy and fuel sources are renewable and some are not.

Clarification Statements:

- Examples of renewable energy resources could include wind energy, water behind dams, tides, and sunlight.
- Non-renewable energy resources are fossil fuels and nuclear materials.

4-ESS3-2. Evaluate different solutions to reduce the impacts of a natural event such as an earthquake, blizzard, or flood on humans.*

Clarification Statement:

- Examples of solutions could include an earthquake-resistant building or a constructed wetland to mitigate flooding.

Grade 4: Life Science

LS1. From Molecules to Organisms: Structures and Processes

4-LS1-1. Construct an argument that animals and plants have internal and external structures that support their survival, growth, behavior, and reproduction.

Clarification Statements:

- Animal structures can include legs, wings, fins, feathers, trunks, claws, horns, antennae, eyes, ears, nose, heart, stomach, lung, brain, and skin.
- Plant structures can include leaves, roots, stems, bark, branches, flowers, fruit, and seeds.

State Assessment Boundary:

- State assessment will be limited to macroscopic structures.

[4-LS1-2 from NGSS is not included.]

Grade 4: Physical Science

PS3. Energy

4-PS3-1. Use evidence to construct an explanation relating the speed of an object to the energy of that object.

State Assessment Boundaries:

- State assessment will be limited to analysis of kinetic energy.
- Accounting for mass, quantitative measures of changes in the speed of an object, or any precise or quantitative definition of energy is not expected in state assessment.

4-PS3-2. Make observations to show that energy can be transferred from place to place by sound, light, heat, and electric currents.

Clarification Statement:

- Evidence of energy being transferred can include vibrations felt a small distance from a source, a solar-powered toy that moves when placed in direct light, warming a metal object on one end and observing the other end getting warm, and a wire carrying electric energy from a battery to light a bulb.

State Assessment Boundary:

- Quantitative measurements of energy are not expected in state assessment.

4-PS3-3. Ask questions and predict outcomes about the changes in energy that occur when objects collide.

Clarification Statement:

- Changes in energy can include a change in the object's motion, position, and the generation of heat and/or sound.

State Assessment Boundary:

- Analysis of forces or quantitative measurements of energy are not expected in state assessment.

4-PS3-4. Apply scientific principles of energy and motion to test and refine a device that converts kinetic energy to electrical energy or uses stored energy to cause motion or produce light or sound.*

Clarification Statement:

- Sources of stored energy can include water in a bucket or a weight suspended at a height, and a battery.

PS4. Waves and Their Applications in Technologies for Information Transfer

4-PS4-1. Develop a model of a simple mechanical wave (including sound) to communicate that waves (a) are regular patterns of motion along which energy travels and (b) can cause objects to move.

Clarification Statement:

- Examples of models could include diagrams, analogies, and physical models.

State Assessment Boundary:

- Interference effects, electromagnetic waves, or non-periodic waves are not expected in state assessment.

4-PS4-2. Develop a model to describe that light must reflect off an object and enter the eye for the object to be seen.

State Assessment Boundary:

- Specific colors reflected and seen, the cellular mechanisms of vision, angles of incidence and reflection, or how the retina works are not expected in state assessment.

4-PS4-3. Develop and compare multiple ways to transfer information through encoding, sending, receiving, and decoding a pattern.*

Clarification Statement:

- Examples of solutions could include drums sending coded information through sound waves, using a grid of 1s and 0s representing black and white to send information about a picture, and using Morse code to send text.

Grade 4: Technology/Engineering

ETS1. Engineering Design

4.3-5-ETS1-3. Plan and carry out tests of one or more design features of a given model or prototype in which variables are controlled and failure points are considered to identify which features need to be improved. Apply the results of tests to redesign a model or prototype.*

Clarification Statement:

- Examples of design features can include materials, size, shape, and weight.

4.3-5-ETS1-5(MA). Evaluate relevant design features that must be considered in building a model or prototype of a solution to a given design problem.*

[3-5-ETS1-1, 3-5-ETS1-2, and 3-5-ETS1-4(MA) are found in grade 3.]

Grade 5

Connections and Relationships in Systems

In grade 5, students model, provide evidence to support arguments, and obtain and display data about relationships and interactions among observable components of different systems. By studying systems, grade 5 students learn that objects and organisms do not exist in isolation and that animals, plants and their environments are connected to, interact with, and are influenced by each other. They study the relationships between Earth and other nearby objects in the solar system and the impact of those relationships on patterns of events as seen from Earth. They learn about the relationship among elements of Earth's systems through the cycling of water and human practices and processes with Earth's resources. They also learn about the connections and relationships among plants and animals, and the ecosystems within which they live, to show how matter and energy are cycled through these (building on the theme of grade 4). An ability to describe, analyze, and model connections and relationships of observable components of different systems is key to understanding the natural and designed world.

Grade 5: Earth and Space Sciences

ESS1. Earth's Place in the Universe

5-ESS1-1. Use observations, first-hand and from various media, to argue that the Sun is a star that appears larger and brighter than other stars because it is closer to Earth.

State Assessment Boundary:

- Other factors that affect apparent brightness (such as stellar masses, age, or stage) are not expected in state assessment.

5-ESS1-2. Use a model to communicate Earth's relationship to the Sun, Moon, and other stars that explain (a) why people on Earth experience day and night, (b) patterns in daily changes in length and direction of shadows over a day, and (c) changes in the apparent position of the Sun, Moon, and stars at different times during a day, over a month, and over a year.

Clarification Statement:

- Models should illustrate that the Earth, Sun, and Moon are spheres; include orbits of the Earth around the Sun and of the Moon around Earth; and demonstrate Earth's rotation about its axis.

State Assessment Boundary:

- Causes of lunar phases or seasons, or use of Earth's tilt are not expected in state assessment.

ESS2. Earth's Systems

5-ESS2-1. Use a model to describe the cycling of water through a watershed through evaporation, precipitation, absorption, surface runoff, and condensation.

State Assessment Boundary:

- Transpiration or explanations of mechanisms that drive the cycle are not expected in state assessment.

5-ESS2-2. Describe and graph the relative amounts of salt water in the ocean; fresh water in lakes, rivers, and groundwater; and fresh water frozen in glaciers and polar ice caps to provide evidence about the availability of fresh water in Earth's biosphere.

State Assessment Boundary:

- Inclusion of the atmosphere is not expected in state assessment.

ESS3. Earth and Human Activity

5-ESS3-1. Obtain and combine information about ways communities reduce human impact on the Earth's resources and environment by changing an agricultural, industrial, or community practice or process.

Clarification Statement:

- Examples of changed practices or processes include treating sewage, reducing the amounts of materials used, capturing polluting emissions from factories or power plants, and preventing runoff from agricultural activities.

State Assessment Boundary:

- Climate change or social science aspects of practices such as regulation or policy are not expected in state assessment.

5-ESS3-2(MA). Test a simple system designed to filter particulates out of water and propose one change to the design to improve it.*

Grade 5: Life Science

LS1. From Molecules to Organisms: Structures and Processes

5-LS1-1. Ask testable questions about the process by which plants use air, water, and energy from sunlight to produce sugars and plant materials needed for growth and reproduction.

State Assessment Boundary:

- The chemical formula or molecular details about the process of photosynthesis are not expected in state assessment.

LS2. Ecosystems: Interactions, Energy, and Dynamics

5-LS2-1. Develop a model to describe the movement of matter among producers, consumers, decomposers, and the air, water, and soil in the environment to (a) show that plants produce sugars and plant materials, (b) show that animals can eat plants and/or other animals for food, and (c) show that some organisms, including fungi and bacteria, break down dead organisms and recycle some materials back to the air and soil.

Clarification Statement:

- Emphasis is on matter moving throughout the ecosystem.

State Assessment Boundary:

- Molecular explanations, or distinctions among primary, secondary, and tertiary consumers, are not expected in state assessment.

5-LS2-2(MA). Compare at least two designs for a composter to determine which is most likely to encourage decomposition of materials.*

Clarification Statement:

- Measures or evidence of decomposition should be on qualitative descriptions or comparisons.

Grade 5: Physical Science

PS1. Matter and Its Interactions

5-PS1-1. Use a particle model of matter to explain common phenomena involving gases, and phase changes between gas and liquid and between liquid and solid.

Clarification Statement:

- Examples of common phenomena the model should be able to describe include adding air to expand a balloon, compressing air in a syringe, and evaporating water from a salt water solution.

State Assessment Boundary:

- Atomic-scale mechanisms of evaporation and condensation or defining unseen particles are not expected in state assessment.

5-PS1-2. Measure and graph the weights (masses) of substances before and after a reaction or phase change to provide evidence that regardless of the type of change that occurs when heating, cooling, or combining substances, the total weight (mass) of matter is conserved.

Clarification Statement:

- Assume that reactions with any gas production are conducted in a closed system.

State Assessment Boundary:

- Distinguishing mass and weight is not expected in state assessment.

5-PS1-3. Make observations and measurements of substances to describe characteristic properties of each, including color, hardness, reflectivity, electrical conductivity, thermal conductivity, response to magnetic forces, and solubility.

Clarification Statements:

- Emphasis is on describing how each substance has a unique set of properties.
- Examples of substances could include baking soda and other powders, metals, minerals, and liquids.

State Assessment Boundary:

- Density, distinguishing mass and weight, or specific tests or procedures are not expected in state assessment.

5-PS1-4. Conduct an experiment to determine whether the mixing of two or more substances results in new substances with new properties (a chemical reaction) or not (a mixture).

PS2. Motion and Stability: Forces and Interactions

5-PS2-1. Support an argument with evidence that the gravitational force exerted by Earth on objects is directed toward Earth's center.

State Assessment Boundary:

- Mathematical representations of gravitational force are not expected in state assessment.

PS3. Energy

5-PS3-1. Use a model to describe that the food animals digest (a) contains energy that was once energy from the Sun, and (b) provides energy and nutrients for life processes, including body repair, growth, motion, body warmth, and reproduction.

Clarification Statement:

- Examples of models could include diagrams and flow charts.

State Assessment Boundary:

- Details of cellular respiration, ATP, or molecular details of the process of photosynthesis or respiration are not expected in state assessment.

ETS3. Technological Systems

5.3-5-ETS3-1(MA). Use informational text to provide examples of improvements to existing technologies (innovations) and the development of new technologies (inventions). Recognize that technology is any modification of the natural or designed world done to fulfill human needs or wants.

5.3-5-ETS3-2(MA). Use sketches or drawings to show how each part of a product or device relates to other parts in the product or device.*

Grades 6–8: Overview of Science and Engineering Practices

Active engagement of middle school students with the science and engineering practices is critical: students generally make up their minds about whether they identify with science and engineering by the time they leave grade 8, and whether they will pursue these fields in high school and beyond. Students must have opportunities to develop the skills necessary for a meaningful progression of development in order to engage in scientific and technical reasoning so critical to success in civic life, postsecondary education, and careers. Inclusion of science and engineering practices in standards only speaks to the types of performances students should be able to demonstrate at the end of instruction at a particular grade; the standards do not limit what educators and students should or can be engaged in through a well-rounded curriculum.

Standards for grades 6 through 8 integrate all eight science and engineering practices. Students' understanding of and ability with each practice gets more detailed and sophisticated through middle school. For example, by the end of middle school, students can identify limitations of a particular model, including limitations of its accuracy, what features are included (or not), and limitations of what phenomena or outcomes it can predict. Students can develop models of varying levels of detail and accuracy and can identify when a situation calls for a conceptual model with little detail or a specific model with attention to accuracy, such as for making predictions of particular events.

Some examples of specific skills students should develop in these grades:

1. Define criteria and constraints of a design problem with precision.
2. Develop a model to describe cycling of matter in an ecosystem; develop a model that describes and predicts changes in particle motion and spatial arrangement during phase changes; develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena.
3. Conduct an investigation to show relationships among energy transfer, type of matter, and kinetic energy of particles; conduct an experiment to show that many materials are mixtures.
4. Examine and interpret data to describe the role human activities have played in the rise of global temperatures over time; construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships; distinguish between causal and correlational relationships in data; consider limitations of data analysis.
5. Describe, including through probability statements and proportional reasoning, the process of natural selection; use data and graphs to describe relationships among kinetic energy, mass, and speed of an object.
6. Construct an explanation using evidence for how Earth's surface has changed over time; apply scientific reasoning to show why the data or evidence is adequate for the explanation.
7. Construct an argument based on evidence for how environmental and genetic factors influence organism growth; respectfully provide and receive critiques about one's arguments, procedures, and models by citing relevant evidence with pertinent detail.
8. Synthesize and communicate information about artificial selection; obtain and communicate information on how past geologic events are analyzed to make future predictions.

While presented as distinct skill sets, the eight practices intentionally overlap and interconnect. Skills such as those outlined above should be reflected in curricula and instruction that engage students in an integrated use of the practices. See the Science and Engineering Practices Progression Matrix (Appendix I) for more information, including particular skills for students in grades 6–8.

Grade 6

Structure and Function

The integration of Earth and space, life, and physical sciences with technology/engineering gives grade 6 students relevant and engaging opportunities with natural phenomena and design problems that highlight the relationship of structure and function in the world around them. Students relate structure and function through analyzing the macro- and microscopic world, such as Earth features and processes, the role of cells and anatomy in supporting living organisms, and properties of materials and waves. Students use models and provide evidence to make claims and explanations about structure-function relationships in different STE domains.

Grade 6: Earth and Space Sciences

ESS1. Earth's Place in the Universe

6.MS-ESS1-1a. Develop and use a model of the Earth-Sun-Moon system to explain the causes of lunar phases and eclipses of the Sun and Moon.

Clarification Statement:

- Examples of models can be physical, graphical, or conceptual and should emphasize relative positions and distances.

6.MS-ESS1-4. Analyze and interpret rock layers and index fossils to determine the relative ages of rock formations that result from processes occurring over long periods of time.

Clarification Statements:

- Analysis includes laws of superposition and crosscutting relationships limited to minor displacement faults that offset layers.
- Processes that occur over long periods of time include changes in rock types through weathering, erosion, heat, and pressure.

State Assessment Boundary:

- Strata sequences that have been reordered or overturned, names of specific periods or epochs and events within them, or the identification and naming of minerals or rock types are not expected in state assessment.

6.MS-ESS1-5(MA). Use graphical displays to illustrate that Earth and its solar system are one of many in the Milky Way galaxy, which is one of billions of galaxies in the universe.

Clarification Statement:

- Graphical displays can include maps, charts, graphs, and data tables.

[MS-ESS1-1b and MS-ESS1-2 are found in grade 8. MS-ESS1-3 from NGSS is not included.]

ESS2. Earth's Systems

6.MS-ESS2-3. Analyze and interpret maps showing the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence that Earth's plates have moved great distances, collided, and spread apart.

Clarification Statement:

- Maps may show 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), similar to Wegener's visuals.

State Assessment Boundary:

- Mechanisms for plate motion or paleomagnetic anomalies in oceanic and continental crust are not expected in state assessment.

[MS-ESS2-2 and MS-ESS2-4 are found in grade 7. MS-ESS2-1, MS-ESS2-5, and MS-ESS2-6 are found in grade 8.]

Grade 6: Life Science

LS1. From Molecules to Organisms: Structures and Processes

6.MS-LS1-1. Provide evidence that all organisms (unicellular and multicellular) are made of cells.

Clarification Statement:

- Evidence can be drawn from multiple types of organisms, such as plants, animals, and bacteria.

6.MS-LS1-2. Develop and use a model to describe how parts of cells contribute to the cellular functions of obtaining food, water, and other nutrients from its environment, disposing of wastes, and providing energy for cellular processes.

Clarification Statement:

- Parts of plant and animal cells include (a) the nucleus, which contains a cell's genetic material and regulates its activities; (b) chloroplasts, which produce necessary food (sugar) and oxygen through photosynthesis (in plants); (c) mitochondria, which release energy from food through cellular respiration; (d) vacuoles, which store materials, including water, nutrients, and waste; (e) the cell membrane, which is a selective barrier that enables nutrients to enter the cell and wastes to be expelled; and (f) the cell wall, which provides structural support (in plants).

State Assessment Boundary:

- Specific biochemical steps or chemical processes, the role of ATP, active transport processes involving the cell membrane, or identifying or comparing different types of cells are not expected in state assessment.

6.MS-LS1-3. Construct an argument supported by evidence that the body systems interact to carry out essential functions of life.

Clarification Statements:

- Emphasis is on the functions and interactions of the body systems, not specific body parts or organs.
- An argument should convey that different types of cells can join together to form specialized tissues, which in turn may form organs that work together as body systems.
- Body systems to be included are the circulatory, digestive, respiratory, excretory, muscular/skeletal, and nervous systems.
- Essential functions of life include obtaining food and other nutrients (water, oxygen, minerals), releasing energy from food, removing wastes, responding to stimuli, maintaining internal conditions, and growing/developing.
- An example of interacting systems could include the respiratory system taking in oxygen from the environment which the circulatory system delivers to cells for cellular respiration, or the digestive system taking in nutrients which the circulatory system transports to cells around the body.

State Assessment Boundaries:

- The mechanism of one body system independent of others or the biochemical processes involved in body systems are not expected in state assessment.
- Describing the function or comparing different types of cells, tissues, or organs are not expected in state assessment.

[MS-LS1-4 is found in grade 7. MS-LS1-5 and MS-LS1-7 are found in grade 8. MS-LS1-6 and MS-LS1-8 from NGSS are not included.]

LS4. Biological Evolution: Unity and Diversity

6.MS-LS4-1. Analyze and interpret evidence from the fossil record to describe organisms and their environment, extinctions, and changes to life forms throughout the history of Earth.

Clarification Statement:

- Examples of evidence include sets of fossils that indicate a specific type of environment, anatomical structures that indicate the function of an organism in the environment, and fossilized tracks that indicate behavior of organisms.

State Assessment Boundary:

- Names of individual species, geological eras in the fossil record, or mechanisms for extinction or speciation are not expected in state assessment.

6.MS-LS4-2. Construct an argument using anatomical structures to support evolutionary relationships among and between fossil organisms and modern organisms.

Clarification Statement:

- Evolutionary relationships include (a) some organisms have similar traits with similar functions because they were inherited from a common ancestor, (b) some organisms have similar traits that serve similar functions because they live in similar environments, and (c) some organisms have traits inherited from common ancestors that no longer serve their original function because their environments are different than their ancestors' environments.

[MS-LS4-4 and MS-LS4-5 are found in grade 8. MS-LS4-3 and MS-LS4-6 from NGSS are not included.]

Grade 6: Physical Science

PS1. Matter and Its Interactions

6.MS-PS1-6. Plan and conduct an experiment involving exothermic and endothermic chemical reactions to measure and describe the release or absorption of thermal energy.

Clarification Statements:

- Emphasis is on describing transfer of energy to and from the environment.
- Examples of chemical reactions could include dissolving ammonium chloride or calcium chloride.

6.MS-PS1-7(MA). Use a particulate model of matter to explain that density is the amount of matter (mass) in a given volume. Apply proportional reasoning to describe, calculate, and compare relative densities of different materials.

6.MS-PS1-8(MA). Conduct an experiment to show that many materials are mixtures of pure substances that can be separated by physical means into their component pure substances.

Clarification Statement:

- Examples of common mixtures include salt water, oil and vinegar, milk, and air.

[MS-PS1-1, MS-PS1-2, MS-PS1-4, and MS-PS1-5 are found in grade 8. MS-PS1-3 from NGSS is not included.]

PS2. Motion and Stability: Forces and Interactions

6.MS-PS2-4. Use evidence to support the claim that gravitational forces between objects are attractive and are only noticeable when one or both of the objects have a very large mass.

Clarification Statement:

- Examples of objects with very large masses include the Sun, Earth, and other planets.

State Assessment Boundary:

- Newton's law of gravitation or Kepler's laws are not expected in state assessment.

[MS-PS2-3 and MS-PS2-5 are found in grade 7. MS-PS2-1 and MS-PS2-2 are found in grade 8.]

PS4. Waves and Their Applications in Technologies for Information Transfer

6.MS-PS4-1. Use diagrams of a simple wave to explain that (a) a wave has a repeating pattern with a specific amplitude, frequency, and wavelength, and (b) the amplitude of a wave is related to the energy of the wave.

State Assessment Boundaries:

- Electromagnetic waves are not expected in state assessment.
- State assessment will be limited to standard repeating waves.

6.MS-PS4-2. Use diagrams and other models to show that both light rays and mechanical waves are reflected, absorbed, or transmitted through various materials.

Clarification Statements:

- Materials may include solids, liquids, and gases.
- Mechanical waves (including sound) need a material (medium) through which they are transmitted.
- Examples of models could include drawings, simulations, and written descriptions.

State Assessment Boundary:

- State assessment will be limited to qualitative applications.

6.MS-PS4-3. Present qualitative scientific and technical information to support the claim that digitized signals (sent as wave pulses representing 0s and 1s) can be used to encode and transmit information.

State Assessment Boundary:

- Binary counting or the specific mechanism of any given device are not expected in state assessment.

Grade 6: Technology/Engineering

ETS1. Engineering Design

6.MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution. Include potential impacts on people and the natural environment that may limit possible solutions.*

6.MS-ETS1-5(MA). Create visual representations of solutions to a design problem. Accurately interpret and apply scale and proportion to visual representations.*

Clarification Statements:

- Examples of visual representations can include sketches, scaled drawings, and orthographic projections.
- Examples of scale can include ¼″ = 1′0″ and 1 cm = 1 m.

6.MS-ETS1-6(MA). Communicate a design solution to an intended user, including design features and limitations of the solution.

Clarification Statement:

- Examples of intended users can include students, parents, teachers, manufacturing personnel, engineers, and customers.

[MS-ETS1-2, MS-ETS1-4, and MS-ETS1-7(MA) are found in grade 7. MS-ETS1-3 from NGSS is not included.]

ETS2. Materials, Tools, and Manufacturing

6.MS-ETS2-1(MA). Analyze and compare properties of metals, plastics, wood, and ceramics, including flexibility, ductility, hardness, thermal conductivity, electrical conductivity, and melting point.

6.MS-ETS2-2(MA). Given a design task, select appropriate materials based on specific properties needed in the construction of a solution.*

Clarification Statement:

- Examples of materials can include metals, plastics, wood, and ceramics.

6.MS-ETS2-3(MA). Choose and safely use appropriate measuring tools, hand tools, fasteners, and common hand-held power tools used to construct a prototype.*

Clarification Statements:

- Examples of measuring tools include a tape measure, a meter stick, and a ruler.
- Examples of hand tools include a hammer, a screwdriver, a wrench, and pliers.
- Examples of fasteners include nails, screws, nuts and bolts, staples, glue, and tape.
- Examples of common power tools include jigsaw, drill, and sander.

[MS-ETS2-4(MA), and MS-ETS2-5(MA) are found in grade 8.]

Grade 7

Systems and Cycles

Students in grade 7 focus on systems and cycles using their understanding of structures and functions, connections and relationships in systems, and flow of matter and energy developed in earlier grades. A focus on systems requires students to apply concepts and skills across disciplines, since most natural and designed systems and cycles are complex and interactive. They gain experience with plate tectonics, interactions of humans and Earth processes, organism systems to support and propagate life, ecosystem dynamics, motion and energy systems, and key technological systems used by society. Through grade 7, students begin a process of moving from a more concrete to an abstract perspective, since many of the systems and cycles studied are not directly observable or experienced. This also creates a foundation for exploring cause and effect relationships in more depth in grade 8.

Grade 7: Earth and Space Sciences

ESS2. Earth's Systems

7.MS-ESS2-2. Construct an explanation based on evidence for how Earth's surface has changed over scales that range from local to global in size.

Clarification Statements:

- Examples of processes occurring over large, global spatial scales include plate motion, formation of mountains and ocean basins, and ice ages.
- Examples of changes occurring over small, local spatial scales include earthquakes and seasonal weathering and erosion.

7.MS-ESS2-4. Develop a model to explain how the energy of the Sun and Earth's gravity drive the cycling of water, including changes of state, as it moves through multiple pathways in Earth's hydrosphere.

Clarification Statement:

- Examples of models can be conceptual or physical.

State Assessment Boundary:

- A quantitative understanding of the latent heats of vaporization and fusion is not expected in state assessment.

[MS-ESS2-3 is found in grade 6. MS-ESS2-1, MS-ESS2-5, and MS-ESS2-6 are found in grade 8.]

ESS3. Earth and Human Activity

7.MS-ESS3-2. Obtain and communicate information on how data from past geologic events are analyzed for patterns and used to forecast the location and likelihood of future catastrophic events.

Clarification Statements:

- Geologic events include earthquakes, volcanic eruptions, floods, and landslides.
- Examples of data typically analyzed can include the locations, magnitudes, and frequencies of the natural hazards.

State Assessment Boundary:

- Active analysis of data or forecasting is not expected in state assessment.

7.MS-ESS3-4. Construct an argument supported by evidence that human activities and technologies can mitigate the impact of increases in human population and per capita consumption of natural resources on the environment.

Clarification Statements:

- Arguments should be based on examining historical data such as population graphs, natural resource distribution maps, and water quality studies over time.
- Examples of negative impacts can include changes to the amount and quality of natural resources such as water, mineral, and energy supplies.

[MS-ESS3-1 and MS-ESS3-5 are found in grade 8. MS-ESS3-3 from NGSS has been merged with MS-ESS3-4.]

Grade 7: Life Science

LS1. From Molecules to Organisms: Structures and Processes

7.MS-LS1-4. Construct an explanation based on evidence for how characteristic animal behaviors and specialized plant structures increase the probability of successful reproduction of animals and plants.

Clarification Statements:

- Examples of animal behaviors that affect the probability of animal reproduction could include nest building to protect young from cold, herding of animals to protect young from predators, and vocalizations and colorful plumage to attract mates for breeding.
- Examples of animal behaviors that affect the probability of plant reproduction could include (a) transferring pollen or seeds and (b) creating conditions for seed germination and growth.
- Examples of plant structures that affect the probability of plant reproduction could include bright flowers attracting butterflies that transfer pollen, flower nectar, and odors that attract insects that transfer pollen, and hard shells on nuts that squirrels bury.

State Assessment Boundary:

- Natural selection is not expected in state assessment.

[MS-LS1-1, MS-LS1-2, and MS-LS1-3 are found in grade 6. MS-LS1-5 and MS-LS1-7 are found in grade 8. MS-LS1-6 and MS-LS1-8 from NGSS are not included.]

LS2. Ecosystems: Interactions, Energy, and Dynamics

7.MS-LS2-1. Analyze and interpret data to provide evidence for the effects of periods of abundant and scarce resources on the growth of organisms and the size of populations in an ecosystem.

7.MS-LS2-2. Describe how relationships among and between organisms in an ecosystem can be competitive, predatory, parasitic, and mutually beneficial and that these interactions are found across multiple ecosystems.

Clarification Statement:

- Emphasis is on describing consistent patterns of interactions in different ecosystems in terms of relationships among and between organisms.

7.MS-LS2-3. Develop a model to describe that matter and energy are transferred among living and nonliving parts of an ecosystem and that both matter and energy are conserved through these processes.

Clarification Statements:

- Cycling of matter should include the role of photosynthesis, cellular respiration, and decomposition, as well as transfer among producers, consumers (primary, secondary, and tertiary), and decomposers.
- Models may include food webs and food chains.

State Assessment Boundary:

- Cycling of specific atoms (such as carbon or oxygen), or the biochemical steps of photosynthesis, cellular respiration, and decomposition are not expected in state assessment.

7.MS-LS2-4. Analyze data to provide evidence that disruptions (natural or human-made) to any physical or biological component of an ecosystem can lead to shifts in all its populations.

Clarification Statement:

- Focus should be on ecosystem characteristics varying over time, including disruptions such as hurricanes, floods, wildfires, oil spills, and construction.

7.MS-LS2-5. Evaluate competing design solutions for protecting an ecosystem. Discuss benefits and limitations of each design.*

Clarification Statements:

- Examples of design solutions could include water, land, and species protection and the prevention of soil erosion.
- Examples of design solution constraints could include scientific, economic, and social considerations.

7.MS-LS2-6(MA). Explain how changes to the biodiversity of an ecosystem—the variety of species found in the ecosystem—may limit the availability of resources humans use.

Clarification Statement:

Examples of resources can include food, energy, medicine, and clean water.

Grade 7: Physical Science

PS2. Motion and Stability: Forces and Interactions

7.MS-PS2-3. Analyze data to describe the effect of distance and magnitude of electric charge on the strength of electric forces.

Clarification Statement:

- Includes both attractive and repulsive forces.

State Assessment Boundaries:

- State assessment will be limited to proportional reasoning.
- Calculations using Coulomb's law or interactions of sub-atomic particles are not expected in state assessment.

7.MS-PS2-5. Use scientific evidence to argue that fields exist between objects with mass, between magnetic objects, and between electrically charged objects that exert force on each other even though the objects are not in contact.

Clarification Statement:

- Emphasis is on evidence that demonstrates the existence of fields, limited to gravitational, electric, and magnetic fields.

State Assessment Boundary:

- Calculations of force are not expected in state assessment.

[MS-PS2-4 is found in grade 6. MS-PS2-1 and MS-PS2-2 are found in grade 8.]

PS3. Energy

7.MS-PS3-1. Construct and interpret data and graphs to describe the relationships among kinetic energy, mass, and speed of an object.

Clarification Statements:

- Examples could include riding a bicycle at different speeds and rolling different-sized rocks downhill.
- Consider relationships between kinetic energy vs. mass and kinetic energy vs. speed separate from each other; emphasis is on the difference between the linear and exponential relationships.

State Assessment Boundary:

- Calculation or manipulation of the formula for kinetic energy is not expected in state assessment.

7.MS-PS3-2. Develop a model to describe the relationship between the relative positions of objects interacting at a distance and their relative potential energy in the system.

Clarification Statements:

- Examples of objects within systems interacting at varying distances could include Earth and either a roller coaster cart at varying positions on a hill or objects at varying heights on shelves, changing the direction/orientation of a magnet, and a balloon with static electrical charge being brought closer to a stream of water.
- Examples of models could include representations, diagrams, pictures, and written descriptions of systems.

State Assessment Boundaries:

- State assessment will be limited to electric, magnetic, and gravitational interactions and to interactions of two objects at a time.
- Calculations of potential energy are not expected in state assessment.

7.MS-PS3-3. Apply scientific principles of energy and heat transfer to design, construct, and test a device to minimize or maximize thermal energy transfer.*

Clarification Statement:

- Examples of devices could include an insulated box, a solar cooker, and a vacuum flask.

State Assessment Boundary:

- Accounting for specific heat or calculations of the total amount of thermal energy transferred is not expected in state assessment.

7.MS-PS3-4. Conduct an investigation to determine the relationships among the energy transferred, how well the type of matter retains or radiates heat, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.

State Assessment Boundary:

- Calculations of specific heat or the total amount of thermal energy transferred are not expected in state assessment.

7.MS-PS3-5. Present evidence to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

Clarification Statement:

- Examples of empirical evidence could include an inventory or other representation of the energy before and after the transfer in the form of temperature changes or motion of an object.

State Assessment Boundary:

- Calculations of energy are not expected in state assessment.

7.MS-PS3-6(MA). Use a model to explain how thermal energy is transferred out of hotter regions or objects and into colder ones by convection, conduction, and radiation.

7.MS-PS3-7(MA). Use informational text to describe the relationship between kinetic and potential energy and illustrate conversions from one form to another.

Clarification Statement:

- Types of kinetic energy include motion, sound, thermal, and light; types of potential energy include gravitational, elastic, and chemical.

Grade 7: Technology/Engineering

ETS1. Engineering Design

7.MS-ETS1-2. Evaluate competing solutions to a given design problem using a decision matrix to determine how well each meets the criteria and constraints of the problem. Use a model of each solution to evaluate how variations in one or more design features, including size, shape, weight, or cost, may affect the function or effectiveness of the solution.*

7.MS-ETS1-4. Generate and analyze data from iterative testing and modification of a proposed object, tool, or process to optimize the object, tool, or process for its intended purpose.*

7.MS-ETS1-7(MA). Construct a prototype of a solution to a given design problem.*

[MS-ETS1-1, MS-ETS1-5(MA), and MS-ETS1-6(MA) are found in grade 6. MS-ETS1-3 from NGSS is not included.]

ETS3. Technological Systems

7.MS-ETS3-1(MA). Explain the function of a communication system and the role of its components, including a source, encoder, transmitter, receiver, decoder, and storage.

7.MS-ETS3-2(MA). Compare the benefits and drawbacks of different communication systems.

Clarification Statements:

- Examples of communications systems can include radio, television, print, and Internet.
- Examples of benefits and drawbacks can include speed of communication, distance or range, number of people reached, audio only vs. audio and visual, and one-way vs. two-way communication.

7.MS-ETS3-3(MA). Research and communicate information about how transportation systems are designed to move people and goods using a variety of vehicles and devices. Identify and describe subsystems of a transportation vehicle, including structural, propulsion, guidance, suspension, and control subsystems.

Clarification Statements:

- Examples of design elements include vehicle shape to maximize cargo or passenger capacity, terminals, travel lanes, and communications/controls.
- Examples of vehicles can include a car, sailboat, and small airplane.

7.MS-ETS3-4(MA). Show how the components of a structural system work together to serve a structural function. Provide examples of physical structures and relate their design to their intended use.

Clarification Statements:

- Examples of components of a structural system could include foundation, decking, wall, and roofing.
- Explanations of function should include identification of live vs. dead loads and forces of tension, torsion, compression, and shear.
- Examples of uses include carrying loads and forces across a span (such as a bridge), providing livable space (such as a house or office building), and providing specific environmental conditions (such as a greenhouse or cold storage).

State Assessment Boundary:

- Calculations of magnitude or direction of loads or forces are not expected in state assessment.

7.MS-ETS3-5(MA). Use the concept of systems engineering to model inputs, processes, outputs, and feedback among components of a transportation, structural, or communication system.

Grade 8

Cause and Effect

Grade 8 students use more robust abstract thinking skills to explain causes of complex phenomena and systems. Many causes are not immediately or physically visible to students. An understanding of cause and effect of key natural phenomena and designed processes allows students to explain patterns and make predictions about future events. In grade 8 these include, for example, causes of seasons and tides; causes of plate tectonics and weather or climate; the role of genetics in reproduction, heredity, and artificial selection; and how atoms and molecules interact to explain the substances that make up the world and how materials change. Being able to analyze phenomena for evidence of causes and processes that often cannot be seen, and being able to conceptualize and describe those, is a significant outcome for grade 8 students.

Grade 8: Earth and Space Sciences

ESS1. Earth's Place in the Universe

8.MS-ESS1-1b. Develop and use a model of the Earth-Sun system to explain the cyclical pattern of seasons, which includes Earth's tilt and differential intensity of sunlight on different areas of Earth across the year.

Clarification Statement:

- Examples of models can be physical or graphical.

8.MS-ESS1-2. Explain the role of gravity in ocean tides, the orbital motions of planets, their moons, and asteroids in the solar system.

State Assessment Boundary:

- Kepler's laws of orbital motion or the apparent retrograde motion of the planets as viewed from Earth are not expected in state assessment.

[MS-ESS1-1a, MS-ESS1-4, and MS-ESS1-5 are found in grade 6. MS-ESS1-3 from NGSS is not included.]

ESS2. Earth's Systems

8.MS-ESS2-1. Use a model to illustrate that energy from Earth's interior drives convection that cycles Earth's crust, leading to melting, crystallization, weathering, and deformation of large rock formations, including generation of ocean sea floor at ridges, submergence of ocean sea floor at trenches, mountain building, and active volcanic chains.

Clarification Statement:

- The emphasis is on large-scale cycling resulting from plate tectonics.

8.MS-ESS2-5. Interpret basic weather data to identify patterns in air mass interactions and the relationship of those patterns to local weather.

Clarification Statements:

- Data includes temperature, pressure, humidity, precipitation, and wind.
- Examples of patterns can include air masses flow from regions of high pressure to low pressure, and how sudden changes in weather can result when different air masses collide.
- Data can be provided to students (such as in weather maps, data tables, diagrams, or visualizations) or obtained through field observations or laboratory experiments.

State Assessment Boundary:

- Specific names of cloud types or weather symbols used on weather maps are not expected in state assessment.

8.MS-ESS2-6. Describe how interactions involving the ocean affect weather and climate on a regional scale, including the influence of the ocean temperature as mediated by energy input from the Sun and energy loss due to evaporation or redistribution via ocean currents.

Clarification Statement:

- A regional scale includes a state or multi-state perspective.

State Assessment Boundary:

- Koppen Climate Classification names are not expected in state assessment.

[MS-ESS2-3 is found in grade 6. MS-ESS2-2 and MS-ESS2-4 are found in grade 7.]

ESS3. Earth and Human Activity

8.MS-ESS3-1. Analyze and interpret data to explain that the Earth's mineral and fossil fuel resources are unevenly distributed as a result of geologic processes.

Clarification Statement:

- Examples of uneven distributions of resources can include where petroleum is generally found (locations of the burial of organic marine sediments and subsequent geologic traps), and where metal ores are generally found (locations of past volcanic and hydrothermal activity).

8.MS-ESS3-5. Examine and interpret data to describe the role that human activities have played in causing the rise in global temperatures over the past century.

Clarification Statements:

- Examples of human activities include fossil fuel combustion, deforestation, and agricultural activity.
- Examples of evidence can include tables, graphs, and maps of global and regional temperatures; atmospheric levels of gases such as carbon dioxide and methane; and the rates of human activities.

[MS-ESS3-2 and MS-ESS3-4 are found in grade 7. MS-ESS3-3 from NGSS has been merged with MS-ESS3-4.]

Grade 8: Life Science

LS1. From Molecules to Organisms: Structures and Processes

8.MS-LS1-5. Construct an argument based on evidence for how environmental and genetic factors influence the growth of organisms.

Clarification Statements:

- Examples of environmental conditions could include availability of food, light, space, and water.
- Examples of genetic factors could include the genes responsible for size differences in different breeds of dogs, such as Great Danes and Chihuahuas.
- Examples of environmental factors could include drought decreasing plant growth, fertilizer increasing plant growth, and fish growing larger in large ponds than they do in small ponds.
- Examples of both genetic and environmental factors could include different varieties of plants growing at different rates in different conditions.

State Assessment Boundary:

- Methods of reproduction, genetic mechanisms, gene regulation, biochemical processes, or natural selection are not expected in state assessment.

8.MS-LS1-7. Use informational text to describe that food molecules, including carbohydrates, proteins, and fats, are broken down and rearranged through chemical reactions forming new molecules that support cell growth and/or release of energy.

State Assessment Boundary:

- Specific details of the chemical reaction for cellular respiration, biochemical steps of breaking down food, or the resulting molecules (e.g., carbohydrates are broken down into monosaccharides) are not expected in state assessment.

[MS-LS1-1, MS-LS1-2, and MS-LS1-3 are found in grade 6. MS-LS1-4 is found in grade 7. MS-LS1-6 and MS-LS1-8 from NGSS are not included.]

LS3. Heredity: Inheritance and Variation of Traits

8.MS-LS3-1. Develop and use a model to describe that structural changes to genes (mutations) may or may not result in changes to proteins, and if there are changes to proteins there may be harmful, beneficial, or neutral changes to traits.

Clarification Statements:

- An example of a beneficial change to the organism may be a strain of bacteria becoming resistant to an antibiotic.
- A harmful change could be the development of cancer; a neutral change may change the hair color of an organism with no direct consequence.

State Assessment Boundary:

- Specific changes at the molecular level (e.g., amino acid sequence change), mechanisms for protein synthesis, or specific types of mutations are not expected in state assessment.

8.MS-LS3-2. Construct an argument based on evidence for how asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation. Compare and contrast advantages and disadvantages of asexual and sexual reproduction.

Clarification Statements:

- Examples of an advantage of sexual reproduction can include genetic variation when the environment changes or a disease is introduced, while examples of an advantage of asexual reproduction can include not using energy to find a mate and fast reproduction rates.
- Examples of a disadvantage of sexual reproduction can include using resources to find a mate, while a disadvantage in asexual reproduction can be the lack of genetic variation when the environment changes or a disease is introduced.

8.MS-LS3-3(MA). Communicate through writing and in diagrams that chromosomes contain many distinct genes and that each gene holds the instructions for the production of specific proteins, which in turn affects the traits of an individual.

State Assessment Boundary:

- Specific changes at the molecular level or mechanisms for protein synthesis are not expected in state assessment.

8.MS-LS3-4(MA). Develop and use a model to show that sexually reproducing organisms have two of each chromosome in their cell nuclei, and hence two variants (alleles) of each gene that can be the same or different from each other, with one random assortment of each chromosome passed down to offspring from both parents.

Clarification Statement:

- Examples of models can include Punnett squares, diagrams (e.g., simple pedigrees), and simulations.

State Assessment Boundary:

- State assessment will limit inheritance patterns to dominant-recessive alleles only.

LS4. Biological Evolution: Unity and Diversity

8.MS-LS4-4. Use a model to describe the process of natural selection, in which genetic variations of some traits in a population increase some individuals' likelihood of surviving and reproducing in a changing environment. Provide evidence that natural selection occurs over many generations.

Clarification Statements:

- The model should include simple probability statements and proportional reasoning.
- Examples of evidence can include Darwin's finches, necks of giraffes, and peppered moths.

State Assessment Boundary:

- Specific conditions that lead to natural selection are not expected in state assessment.

8.MS-LS4-5. Synthesize and communicate information about artificial selection, or the ways in which humans have changed the inheritance of desired traits in organisms.

Clarification Statement:

- Emphasis is on the influence of humans on genetic outcomes in artificial selection (such as genetic modification, animal husbandry, and gene therapy).

[MS-LS4-1 and MS-LS4-2 are found in grade 6. MS-LS4-3 and MS-LS4-6 from NGSS are not included.]

Grade 8: Physical Science

PS1. Matter and Its Interactions

8.MS-PS1-1. Develop a model to describe that (a) atoms combine in a multitude of ways to produce pure substances which make up all of the living and nonliving things that we encounter, (b) atoms form molecules and compounds that range in size from two to thousands of atoms, and (c) mixtures are composed of different proportions of pure substances.

Clarification Statement:

- Examples of molecular-level models could include drawings, three-dimensional ball and stick structures, and computer representations showing different molecules with different types of atoms.

State Assessment Boundary:

- Valence electrons and bonding energy, the ionic nature of subunits of complex structures, complete depictions of all individual atoms in a complex molecule or extended structure, or calculations of proportions in mixtures are not expected in state assessment.

8.MS-PS1-2. Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

Clarification Statements:

- Examples of reactions could include burning sugar or steel wool, fat reacting with sodium hydroxide, and mixing zinc with HCl.
- Properties of substances include density, melting point, boiling point, solubility, flammability, and odor.

8.MS-PS1-4. Develop a model that describes and predicts changes in particle motion, relative spatial arrangement, temperature, and state of a pure substance when thermal energy is added or removed.

Clarification Statements:

- Emphasis is on qualitative molecular-level models of solids, liquids, and gases to show that adding or removing thermal energy increases or decreases kinetic energy of the particles until a change of state occurs.
- Examples of models could include drawings and diagrams.
- Examples of pure substances could include water, carbon dioxide, and helium.

8.MS-PS1-5. Use a model to explain that atoms are rearranged during a chemical reaction to form new substances with new properties. Explain that the atoms present in the reactants are all present in the products and thus the total number of atoms is conserved.

Clarification Statement:

- Examples of models can include physical models or drawings, including digital forms, that represent atoms.

State Assessment Boundary:

- Use of atomic masses, molecular weights, balancing symbolic equations, or intermolecular forces is not expected in state assessment.

[MS-PS1-6, MS-PS1-7(MA), and MS-PS1-8(MA) are found in grade 6. MS-PS1-3 from NGSS is not included.]

PS2. Motion and Stability: Forces and Interactions

8.MS-PS2-1. Develop a model that demonstrates Newton's third law involving the motion of two colliding objects.

State Assessment Boundary:

- State assessment will be limited to vertical or horizontal interactions in one dimension.

8.MS-PS2-2. Provide evidence that the change in an object's speed depends on the sum of the forces on the object (the net force) and the mass of the object.

Clarification Statement:

- Emphasis is on balanced (Newton's first law) and unbalanced forces in a system, qualitative comparisons of forces, mass, and changes in speed (Newton's second law) in one dimension.

State Assessment Boundaries:

- State assessment will be limited to forces and changes in motion in one dimension in an inertial reference frame and to change in one variable at a time.
- The use of trigonometry is not expected in state assessment.

[MS-PS2-4 is found in grade 6. MS-PS2-3 and MS-PS2-5 are found in grade 7.]

Grade 8: Technology/Engineering

ETS2. Materials, Tools, and Manufacturing

8.MS-ETS2-4(MA). Use informational text to illustrate that materials maintain their composition under various kinds of physical processing; however, some material properties may change if a process changes the particulate structure of a material.

Clarification Statements:

- Examples of physical processing can include cutting, forming, extruding, and sanding.
- Examples of changes in material properties can include a non-magnetic iron material becoming magnetic after hammering and a plastic material becoming rigid (less elastic) after heat treatment.

8.MS-ETS2-5(MA). Present information that illustrates how a product can be created using basic processes in manufacturing systems, including forming, separating, conditioning, assembling, finishing, quality control, and safety. Compare the advantages and disadvantages of human vs. computer control of these processes.

[MS-ETS2-1(MA), MS-ETS2-2(MA), and MS-ETS2-3(MA) are found in grade 6.]

High School: Overview of Science and Engineering Practices

The practices in grades 9–12 build on pre-K–8 experiences and progress to more technical and sophisticated applications to the natural and designed world we live in. The integration of science and engineering practices in high school science courses gives students dynamic and relevant opportunities to refine and communicate science understandings to be well prepared for civic life, postsecondary education, and career success. Essential competencies for students by the end of grade 12 include reading and comprehending relevant issues in science to be informed decision-makers. Accurately using mathematics and computation as it applies to daily life and engaging in the practice of modeling to solve real-world problems enables all students to understand and analyze key scientific and technical issues they will be asked to address throughout their lives. Communicating explanations coherently, with evidence from credible sources, is critical to engaging in public discourse.

Inclusion of science and engineering practices in standards only speak to the types of performances students should be able to demonstrate at the end of instruction of a particular course; the standards do not limit what educators and students should or can be engaged in through a well-rounded curriculum.

By the end of high school, students should have an understanding of and ability to apply each science and engineering practice to understand the world around them. Students should have had many opportunities to immerse themselves in the practices and to explore why they are central to the applications of science and engineering. Some examples of these science and engineering practices include:

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.
2. Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.
3. Plan and conduct an investigation, including deciding on the types, amount, and accuracy of data needed to produce reliable measurements, and consider limitations on the precision of the data.
4. Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific questions and engineering problems, using digital tools when feasible.
5. Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world.
6. Apply scientific reasoning, theory, and/or models to link evidence to the claims and assess the extent to which the reasoning and data support the explanation or conclusion.
7. Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence and challenging ideas and conclusions, and determining what additional information is required to solve contradictions.

8. Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media, verifying the data when possible.

While presented as distinct skill sets, the eight practices intentionally overlap and interconnect. Skills like those outlined above should be reflected in curriculum and instruction that engage students in an integrated use of the practices. The introductory courses (grades 9–10) integrate practices into the standards. In upper-level high school courses (grades 11–12), students should be given continued opportunities to develop the practices. See the Science and Engineering Practices Progression Matrix (Appendix I) for more information, including particular skills for students in high school.

High School Earth and Space Science

The high school Earth and space science standards build from middle school and allow grade 9 or 10 students to explain additional and more complex phenomena related to Earth processes and systems, interactions among Earth's systems, and interactions of Earth's systems and human actions. The standards expect students to apply a variety of science and engineering practices to three core ideas of earth and space science:

- The standards about **Earth's place in the universe** help students understand the universe and its stars, Earth and the solar system, and the history of planet Earth. Students examine the processes governing the formation, evolution, and workings of the solar system and universe.
- **Earth's systems** standards help students explain phenomena related to Earth materials and systems, plate tectonics and large-scale system interactions, the roles of water in Earth's surface processes, and weather and climate. Students develop models and explanations for the ways that feedbacks between different Earth systems control the appearance of Earth's surface. Central to this is the tension between internal systems, which are largely responsible for creating land at Earth's surface, and the Sun-driven surface systems that tear down the land through weathering and erosion. Students begin to examine the ways that human activities cause feedbacks that create changes to other systems. Students understand the system interactions that control weather and climate, with a major emphasis on the mechanisms and implications of climate change. Students model the flow of energy between different components of the weather system and chemical cycles such as the carbon cycle.
- Standards about **Earth and human activity** help students understand natural resources, natural hazards, human impact on Earth systems, and global climate change. Students understand the complex and significant interdependencies between humans and the rest of Earth's systems through the impacts of natural hazards, our dependencies on natural resources, and the significant environmental impacts of human activities. Students apply engineering design and the analysis of geoscience data to examine solutions to challenges facing long-term human sustainability on Earth.

Across the high school Earth and space science standards, particular emphasis is placed on **science and engineering practices** of developing and using models; constructing explanations; and obtaining, evaluating, and communicating information. For example, students are expected to be able to use models to describe and predict the relationships between Earth's systems and analyze data to support explanations of Earth processes. They must be able to construct and revise explanations based on valid, reliable, and relevant evidence and apply scientific reasoning to evaluate complex environmental problems such as the relationship between management of natural resources and sustainability or biodiversity. Students are expected to compare, synthesize, evaluate, and communicate information sources about various Earth systems, interactions between Earth and human activity, and the workings of the solar system. The application of these practices across the core ideas gives students a rich grounding in Earth and space science.

ESS1. Earth's Place in the Universe

HS-ESS1-1. Use informational text to explain that the life span of the Sun over approximately 10 billion years is a function of nuclear fusion in its core. Communicate that stars, through nuclear fusion over their life cycle, produce elements from helium to iron and release energy that eventually reaches Earth in the form of radiation.
State Assessment Boundary:

- Specific stages of the life of a star, details of the many different nucleosynthesis pathways for stars of differing masses, or calculations of energy released are not expected in state assessment.

HS-ESS1-2. Describe the astronomical evidence for the Big Bang theory, including the red shift of light from the motion of distant galaxies as an indication that the universe is currently expanding, the cosmic microwave background as the remnant radiation from the Big Bang, and the observed composition of ordinary matter of the universe, primarily found in stars and interstellar gases, which matches that predicted by the Big Bang theory (3/4 hydrogen and 1/4 helium).

HS-ESS1-4. Use Kepler's laws to predict the motion of orbiting objects in the solar system. Describe how orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system.
Clarification Statements:

- Kepler's laws apply to human-made satellites as well as planets, moons, and other objects.
- Calculations involving Kepler's laws of orbital motions should not deal with more than two bodies, nor involve calculus.

HS-ESS1-5. Evaluate evidence of the past and current movements of continental and oceanic crust, the theory of plate tectonics, and relative densities of oceanic and continental rocks to explain why continental rocks are generally much older than rocks of the ocean floor.
Clarification Statement:

- Examples include the ages of oceanic crust (less than 200 million years old) increasing with distance from mid-ocean ridges (a result of plate spreading at divergent boundaries) and the ages of North American continental crust (which can be older than 4 billion years) increasing with distance away from a central ancient core (a result of past plate interactions at convergent boundaries).

[HS-ESS1-6 from NGSS is not included. HS-ESS1-3 from NGSS has been combined with HS-ESS1-1.]

ESS2. Earth's Systems

HS-ESS2-2. Analyze geoscience data to make the claim that one change to Earth's hydrosphere can create feedbacks that cause changes to other Earth systems.
Clarification Statement:

- Examples can include how decreasing the amount of glacial ice reduces the amount of sunlight reflected from Earth's surface, increasing surface temperatures and further reducing the amount of ice; how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; and how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.

HS-ESS2-3. Use a model based on evidence of Earth's interior to describe the cycling of matter due to the outward flow of energy from Earth's interior and gravitational movement of denser materials toward the interior.

Clarification Statements:

- Emphasis is on both a two-dimensional model of Earth, with radial layers determined by density, and a three-dimensional model, which is controlled by gravity and thermal convection.
- Examples of evidence include maps of Earth's three-dimensional structure obtained from seismic waves, records of the rate of change of Earth's magnetic field (as constraints on convection in the outer core), and identification of the composition of Earth's layers from high-pressure laboratory experiments.

HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth's systems over different time scales result in changes in climate. Analyze and interpret data to explain that long-term changes in Earth's tilt and orbit result in cycles of climate change such as Ice Ages.

Clarification Statement:

- Examples of the causes of climate change differ by timescale: large volcanic eruption and ocean circulation over 1–10 years; changes in human activity, ocean circulation, and solar output over tens to hundreds of years; changes to Earth's orbit and the orientation of its axis over tens to hundreds of thousands of years; and long-term changes in atmospheric composition over tens to hundreds of millions of years.

State Assessment Boundary:

- Changes in climate will be limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution in state assessment.

HS-ESS2-5. Describe how the chemical and physical properties of water are important in mechanical and chemical mechanisms that affect Earth materials and surface processes.

Clarification Statements:

- Examples of mechanical mechanisms involving water include stream transportation and deposition, erosion using variations in soil moisture content, and frost wedging by the expansion of water as it freezes.
- Examples of chemical mechanisms involving water include chemical weathering and recrystallization (based on solubility of different materials) and melt generation (based on water lowering the melting temperature of most solids).

HS-ESS2-6. Use a model to describe cycling of carbon through the ocean, atmosphere, soil, and biosphere and how increases in carbon dioxide concentrations due to human activity have resulted in atmospheric and climate changes.

[HS-ESS2-1 has been merged with MS-ESS2-1. HS-ESS2-7 from NGSS is not included.]

ESS3. Earth and Human Activity

HS-ESS3-1. Construct an explanation based on evidence for how the availability of key natural resources and changes due to variations in climate have influenced human activity.

Clarification Statements:

- Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils (such as river deltas), high concentrations of minerals and fossil fuels, and biotic resources (such as fisheries and forests).
- Examples of changes due to variations in climate include changes to sea level and regional patterns of temperature and precipitation.

HS-ESS3-2. Evaluate competing design solutions for minimizing impacts of developing and using energy and mineral resources, and conserving and recycling those resources, based on economic, social, and environmental cost-benefit ratios.*

Clarification Statement:

- Examples include developing best practices for agricultural soil use, mining (for metals, coal, tar sands, and oil shales), and pumping (for petroleum and natural gas).

HS-ESS3-3. Illustrate relationships among management of natural resources, the sustainability of human populations, and biodiversity.

Clarification Statements:

- Examples of factors related to the management of natural resources include costs of resource extraction and waste management, per capita consumption, and the development of new technologies.
- Examples of factors related to human sustainability include agricultural efficiency, levels of conservation, and urban planning.
- Examples of factors related to biodiversity include habitat use and fragmentation, and land and resource conservation.

HS-ESS3-5. Analyze results from global climate models to describe how forecasts are made of the current rate of global or regional climate change and associated future impacts to Earth systems.

Clarification Statement:

- Climate model outputs include both climate changes (such as precipitation and temperature) and associated impacts (such as on sea level, glacial ice volumes, and atmosphere and ocean composition).

[HS-ESS3-4 and HS-ESS3-6 from NGSS is not included.]

High School Biology

The high school biology standards build from middle school and allow grade 9 or 10 students to explain additional and more complex phenomena related to genetics, the functioning of organisms, and interrelationships between organisms, populations, and the environment. The standards expect students to apply a variety of science and engineering practices to four core ideas of biology:

- **From molecules to organisms: structures and processes** standards help students formulate an answer to the question, "How do organisms live and grow?" Students demonstrate that they can use investigations and gather evidence to support explanations of cell function and reproduction. They understand the role of proteins as essential to the work of the cell and living systems. Students can use models to explain photosynthesis, respiration, and the cycling of matter and flow of energy in living organisms. The cellular processes can be used as a model for understanding the hierarchical organization of organisms.
- Standards focused on **ecosystems: interactions, energy, and dynamics** help students formulate an answer to the question, "How and why do organisms interact with their environment, and what are the effects of these interactions?" Students can use mathematical reasoning to demonstrate understanding of fundamental concepts of carrying capacity, factors affecting biodiversity and populations, and the cycling of matter and flow of energy among organisms in an ecosystem. These models support students' conceptual understanding of systems and their ability to develop design solutions to reduce the impact of human activities on the environment and maintain biodiversity.
- **Heredity: inheritance and variation of traits** standards help students formulate answers to the questions: "How are characteristics of one generation passed to the next? How can individuals of the same species and even siblings have different characteristics?" Students are able to ask questions, make and defend a claim, and use concepts of probability to explain the genetic variation in a population. Students demonstrate understanding of why individuals of the same species vary in how they look and function. Students can explain the mechanisms of genetic inheritance and describe the environmental and genetic causes of gene mutation and the alteration of gene expression.
- Standards for **biological evolution: unity and diversity** help students formulate an answer to the question, "What evidence shows that different species are related?" Students construct explanations for the processes of natural selection and evolution and communicate how multiple lines of evidence support these explanations. Students can evaluate evidence of the conditions that may result in new species and understand the role of genetic variation in natural selection. Additionally, students can apply concepts of probability to explain trends in populations as those trends relate to advantageous heritable traits in a specific environment.

The high school biology standards place particular emphasis on **science and engineering practices** of developing and using models; constructing explanations; engaging in argumentation from evidence; and obtaining, evaluating, and communicating information. Students are expected to use multiple types of models, including mathematical models, to make predictions and develop explanations, analyze and identify flaws in the model, and communicate ideas that accurately represent or simulate the biological system. Students are asked to construct and revise explanations and claims based on valid and reliable evidence and apply scientific reasoning to evaluate complex real-world problems such as the effects of human activity on biodiversity and ecosystem health. Students must be able to find and interpret scientific literature to compare, integrate, and evaluate sources and communicate phenomena related to genetics, the functioning of organisms, and interrelationships between organisms, populations, and the environment. The application of these practices across the core ideas gives students a rich grounding in biology.

LS1. From Molecules to Organisms: Structures and Processes

HS-LS1-1. Construct a model of transcription and translation to explain the roles of DNA and RNA that code for proteins that regulate and carry out essential functions of life.

Clarification Statements:

- Proteins that regulate and carry out essential functions of life include enzymes (which speed up chemical reactions), structural proteins (which provide structure and enable movement), and hormones and receptors (which send and receive signals).
- The model should show the double-stranded structure of DNA, including genes as part of DNA's transcribed strand, with complementary bases on the non-transcribed strand.

State Assessment Boundaries:

- Specific names of proteins or specific steps of transcription and translation are not expected in state assessment.
- Cell structures included in transcription and translation will be limited to nucleus, nuclear membrane, and ribosomes for state assessment.

HS-LS1-2. Develop and use a model to illustrate the key functions of animal body systems, including (a) food digestion, nutrient uptake, and transport through the body; (b) exchange of oxygen and carbon dioxide; (c) removal of wastes; and (d) regulation of body processes.

Clarification Statement:

- Emphasis is on the primary function of the following body systems (and structures): digestive (mouth, stomach, small intestine [villi], large intestine, pancreas), respiratory (lungs [alveoli], diaphragm), circulatory (heart, veins, arteries, capillaries), excretory (kidneys, liver, skin), and nervous (neurons, brain, spinal cord).

State Assessment Boundary:

- Chemical reactions in cells, details of particular structures (such as the structure of the neuron), or the identification of specific proteins in cells are not expected in state assessment.

HS-LS1-3. Provide evidence that homeostasis maintains internal body conditions through both body-wide feedback mechanisms and small-scale cellular processes.

Clarification Statements:

- Feedback mechanisms include the promotion of a stimulus through positive feedback (e.g., injured tissues releasing chemicals in blood that activate platelets to facilitate blood clotting), and the inhibition of stimulus through negative feedback (e.g., insulin reducing high blood glucose to normal levels).
- Cellular processes include (a) passive transport and active transport of materials across the cell membrane to maintain specific concentrations of water and other nutrients in the cell and (b) the role of lysosomes in recycling wastes, macromolecules, and cell parts into monomers.

State Assessment Boundary:

- Interactions at the molecular level (for example, how insulin is produced) are not expected in state assessment.

HS-LS1-4. Construct an explanation using evidence for why the cell cycle is necessary for the growth, maintenance, and repair of multicellular organisms. Model the major events of the cell cycle, including (a) cell growth and DNA replication, (b) separation of chromosomes (mitosis), and (c) separation of cell contents.

State Assessment Boundary:

- Specific gene control mechanisms or specific details of each event (e.g., phases of mitosis) are not expected in state assessment.

HS-LS1-5. Use a model to illustrate how photosynthesis uses light energy to transform water and carbon dioxide into oxygen and chemical energy stored in the bonds of sugars and other carbohydrates.

Clarification Statements:

- Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms.
- Examples of models could include diagrams, chemical equations, and conceptual models.

State Assessment Boundary:

- Specific biochemical steps of light reactions or the Calvin Cycle, or chemical structures of molecules are not expected in state assessment.

HS-LS1-6. Construct an explanation based on evidence that organic molecules are primarily composed of six elements, where carbon, hydrogen, and oxygen atoms may combine with nitrogen, sulfur, and phosphorus to form monomers that can further combine to form large carbon-based macromolecules.

Clarification Statements:

- Monomers include amino acids, mono- and disaccharides, nucleotides, and fatty acids.
- Organic macromolecules include proteins, carbohydrates (polysaccharides), nucleic acids, and lipids.

State Assessment Boundary:

- Details of specific chemical reactions or identification of specific macromolecule structures are not expected in state assessment.

HS-LS1-7. Use a model to illustrate that aerobic cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and new bonds form, resulting in new compounds and a net transfer of energy.

Clarification Statements:

- Emphasis is on the conceptual understanding of the inputs and outputs of the process of aerobic cellular respiration.
- Examples of models could include diagrams, chemical equations, and conceptual models.
- The model should include the role of ATP for energy transfer in this process.
- Food molecules include sugars (carbohydrates), fats (lipids), and proteins.

State Assessment Boundary:

- Identification of the steps or specific processes involved in cellular respiration is not expected in state assessment.

LS2. Ecosystems: Interactions, Energy, and Dynamics

HS-LS2-1. Analyze data sets to support explanations that biotic and abiotic factors affect ecosystem carrying capacity.

Clarification Statements:

- Examples of biotic factors could include relationships among individuals (e.g., feeding relationships, symbioses, competition) and disease.
- Examples of abiotic factors could include climate and weather conditions, natural disasters, and availability of resources.
- Example data sets can be derived from simulations or historical data.

HS-LS2-2. Use mathematical representations to support explanations that biotic and abiotic factors affect biodiversity, including genetic diversity within a population and species diversity within an ecosystem.

Clarification Statements:

- Examples of biotic factors could include relationships among individuals (feeding relationships, symbiosis, competition) and disease.
- Examples of abiotic factors could include climate and weather conditions, natural disasters, and availability of resources.
- Examples of mathematical representations include finding the average, determining trends, and using graphical comparisons of multiple sets of data.

HS-LS2-4. Use a mathematical model to describe the transfer of energy from one trophic level to another. Explain how the inefficiency of energy transfer between trophic levels affects the relative number of organisms that can be supported at each trophic level and necessitates a constant input of energy from sunlight or inorganic compounds from the environment.

Clarification Statement:

- The model should illustrate the “10% rule” of energy transfer and show approximate amounts of available energy at each trophic level in an ecosystem (up to five trophic levels).

HS-LS2-5. Use a model that illustrates the roles of photosynthesis, cellular respiration, decomposition, and combustion to explain the cycling of carbon in its various forms among the biosphere, atmosphere, hydrosphere, and geosphere.

Clarification Statements:

- The primary forms of carbon include carbon dioxide, hydrocarbons, waste (dead organic matter), and biomass (organic materials of living organisms).
- Examples of models could include simulations and mathematical models.

State Assessment Boundary:

- The specific chemical steps of respiration, decomposition, and combustion are not expected in state assessment.

HS-LS2-6. Analyze data to show ecosystems tend to maintain relatively consistent numbers and types of organisms even when small changes in conditions occur but that extreme fluctuations in conditions may result in a new ecosystem. Construct an argument supported by evidence that ecosystems with greater biodiversity tend to have greater resistance to change and resilience.

Clarification Statement:

- Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes, such as volcanic eruption, fires, the decline or loss of a keystone species, climate changes, ocean acidification, or sea level rise.

HS-LS2-7. Analyze direct and indirect effects of human activities on biodiversity and ecosystem health, specifically habitat fragmentation, introduction of non-native or invasive species, overharvesting, pollution, and climate change. Evaluate and refine a solution for reducing the impacts of human activities on biodiversity and ecosystem health.*

Clarification Statement:

- Examples of solutions can include captive breeding programs, habitat restoration, pollution mitigation, energy conservation, and ecotourism.

[HS-LS2-3 has been merged with HS-LS2-4 and HS-LS2-5. HS-LS2-8 from NGSS is not included.]

LS3. Heredity: Inheritance and Variation of Traits

HS-LS3-1. Develop and use a model to show how DNA in the form of chromosomes is passed from parents to offspring through the processes of meiosis and fertilization in sexual reproduction.

Clarification Statement:

- The model should demonstrate that an individual's characteristics (phenotype) result, in part, from interactions among the various proteins expressed by one's genes (genotype).

State Assessment Boundary:

- Identification of specific phases of meiosis or the biochemical mechanisms involved are not expected in state assessment.

HS-LS3-2. Make and defend a claim based on evidence that genetic variations (alleles) may result from (a) new genetic combinations via the processes of crossing over and random segregation of chromosomes during meiosis, (b) mutations that occur during replication, and/or (c) mutations caused by environmental factors. Recognize that mutations that occur in gametes can be passed to offspring.

Clarification Statement:

- Examples of evidence of genetic variation can include the work of McClintock in crossing over of maize chromosomes and the development of cancer due to DNA replication errors and UV ray exposure.

State Assessment Boundary:

- Specific phases of meiosis or identification of specific types of mutations are not expected in state assessment.

HS-LS3-3. Apply concepts of probability to represent possible genotype and phenotype combinations in offspring caused by different types of Mendelian inheritance patterns.

Clarification Statements:

- Representations can include Punnett squares, diagrams, pedigree charts, and simulations.
- Inheritance patterns include dominant-recessive, codominance, incomplete dominance, and sex-linked.

HS-LS3-4(MA). Use scientific information to illustrate that many traits of individuals, and the presence of specific alleles in a population, are due to interactions of genetic factors and environmental factors.

Clarification Statements:

- Examples of genetic factors include the presence of multiple alleles for one gene and multiple genes influencing a trait.
- An example of the role of the environment in expressed traits in an individual can include the likelihood of developing inherited diseases (e.g., heart disease, cancer) in relation to exposure to environmental toxins and lifestyle; an example in populations can include the maintenance of the allele for sickle-cell anemia in high frequency in malaria-affected regions because it confers partial resistance to malaria.

State Assessment Boundary:

- Hardy-Weinberg calculations are not expected in state assessment.

LS4. Biological Evolution: Unity and Diversity

HS-LS4-1. Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence, including molecular, anatomical, and developmental similarities inherited from a common ancestor (homologies), seen through fossils and laboratory and field observations.

Clarification Statement:

- Examples of evidence can include the work of Margulis on endosymbiosis, examination of genomes, and analyses of vestigial or skeletal structures.

HS-LS4-2. Construct an explanation based on evidence that Darwin's theory of evolution by natural selection occurs in a population when the following conditions are met: (a) more offspring are produced than can be supported by the environment, (b) there is heritable variation among individuals, and (c) some of these variations lead to differential fitness among individuals as some individuals are better able to compete for limited resources than others.

Clarification Statement:

- Emphasis is on the overall result of an increase in the proportion of those individuals with advantageous heritable traits that are better able to survive and reproduce in the environment.

HS-LS4-4. Research and communicate information about key features of viruses and bacteria to explain their ability to adapt and reproduce in a wide variety of environments.

Clarification Statement:

- Key features include high rate of mutations and the speed of reproduction which produces many generations with high variability in a short time, allowing for rapid adaptation.

State Assessment Boundary:

- Specific types of viral reproduction (e.g., lytic and lysogenic) are not expected in state assessment.

HS-LS4-5. Evaluate models that demonstrate how changes in an environment may result in the evolution of a population of a given species, the emergence of new species over generations, or the extinction of other species due to the processes of genetic drift, gene flow, mutation, and natural selection.

[HS-LS4-3 from NGSS is merged with HS-LS4-2. HS-LS4-6 from NGSS is not included.]

High School Chemistry

The high school chemistry standards build from middle school physical sciences standards. Middle school includes an important transition from macroscopic phenomena to molecular level models that are used to explain and predict energy transformations in phase changes and conservation of matter in chemical changes, including the use of a basic particle model to visualize and represent physical changes of matter. In high school, students consider how structure and composition at sub-atomic scales explain structure-property relationships in chemistry and influence energy transformations and dissipation of energy during chemical and physical changes.

As a discipline that is concerned not only with what we can know but also with what we can do with what we know, chemistry emphasizes **science and engineering practices** related to design and evaluation as well as investigation and modeling. For example, students are challenged to apply chemistry knowledge to designing ways to control the extent of chemical reactions for practical purposes, analyze unknown samples to determine identities and concentrations of possible pollutants, and evaluate the consequences of using different materials for household items. Students are expected to apply mathematical reasoning when considering conservation of matter in chemical reactions and in comparing strength of acid-base solutions. Students apply a variety of science and engineering practices to three disciplinary core ideas of chemistry:

- The major focus of chemistry is on **matter and its interactions.** Students develop both molecular and sub-atomic models of matter and learn to rely on the periodic table as a powerful model for predicting a wide variety of properties of elements and compounds. Students develop greater capacity for building multi-step linear causal explanations by using a combination of the periodic table model and Coulomb's law to predict and explain qualitative comparisons of bond energies. They also consider spatial arrangements of ions in crystal structures and covalent bonds in molecules, and the relative favorability of energy changes required to rearrange components. Students reason about timescales in the context of a collision theory model, and consider how altering external conditions, chemical concentrations, and ways of introducing reactants to a system can be manipulated to control chemical processes. Students refine their understanding of conservation of matter by making quantitative predictions of theoretical yields if reactions are driven to completion using stoichiometric molar proportions and molar mass calculations. They also practice using two major models of reaction processes, the Bronsted-Lowry acid-base reaction model and the oxidation-reduction reaction model, to explain reaction patterns observed in many common phenomena in the natural world.
- Standards for **motion and stability: forces and interactions** help students explain structure-property relationships in terms of forces and interactions, and to consider the energetic stabilities of structures as a driving force in predicting a variety of observable response properties. Water's role as a common solvent is a central example in using molecular-level intermolecular bonding structure arguments to explain the relative solubilities of different ionic compounds. Intermolecular bonding is also explored in rationalizing why some classes of substances are better than others for specific practical uses, and designing molecular level structural specifications of substances that could have desired properties. Students also build on the basic particle model of matter studied in middle school to add quantitative predictions of externally controllable or measurable properties of gases.
- Standards about **energy** help students demonstrate understanding of energy transfer and dissipation of energy in chemical systems. Students rationalize observations of endothermic

and exothermic changes in terms of energy required to break and form chemical bonds when structural rearrangements occur in chemical processes.

PS1. Matter and Its Interactions

HS-PS1-1. Use the periodic table as a model to predict the relative properties of main group elements, including ionization energy and relative sizes of atoms and ions, based on the patterns of electrons in the outermost energy level of each element. Use the patterns of valence electron configurations, core charge, and Coulomb's law to explain and predict general trends in ionization energies, relative sizes of atoms and ions, and reactivity of pure elements.

Clarification Statement:

- Size of ions should be relevant only for predicting strength of ionic bonding.

State Assessment Boundary:

- State assessment will be limited to main group (s and p block) elements.

HS-PS1-2. Use the periodic table model to predict and design simple reactions that result in two main classes of binary compounds, ionic and molecular. Develop an explanation based on given observational data and the electronegativity model about the relative strengths of ionic or covalent bonds.

Clarification Statements:

- Simple reactions include synthesis (combination), decomposition, single displacement, double displacement, and combustion.
- Predictions of reactants and products can be represented using Lewis dot structures, chemical formulas, or physical models.
- Observational data include that binary ionic substances (i.e., substances that have ionic bonds), when pure, are crystalline salts at room temperature (common examples include NaCl, KI, Fe_2O_3); and substances that are liquids and gases at room temperature are usually made of molecules that have covalent bonds (common examples include CO_2, N_2, CH_4, H_2O, C_8H_{18}).

HS-PS1-3. Cite evidence to relate physical properties of substances at the bulk scale to spatial arrangements, movement, and strength of electrostatic forces among ions, small molecules, or regions of large molecules in the substances. Make arguments to account for how compositional and structural differences in molecules result in different types of intermolecular or intramolecular interactions.

Clarification Statements:

- Substances include both pure substances in solid, liquid, gas, and networked forms (such as graphite).
- Examples of bulk properties of substances to compare include melting point and boiling point, density, and vapor pressure.
- Types of intermolecular interactions include dipole-dipole (including hydrogen bonding), ion-dipole, and dispersion forces.

State Assessment Boundary:

- Calculations of vapor pressure by Raoult's law, properties of heterogeneous mixtures, and names and bonding angles in molecular geometries are not expected in state assessment.

HS-PS1-4. Develop a model to illustrate the energy transferred during an exothermic or endothermic chemical reaction based on the bond energy difference between bonds broken (absorption of energy) and bonds formed (release of energy).

Clarification Statement:

- Examples of models may include molecular-level drawings and diagrams of reactions or graphs showing the relative energies of reactants and products.

State Assessment Boundary:

- Calculations using Hess's law are not expected in state assessment.

HS-PS1-5. Construct an explanation based on kinetic molecular theory for why varying conditions influence the rate of a chemical reaction or a dissolving process. Design and test ways to slow down or accelerate rates of processes (chemical reactions or dissolving) by altering various conditions.*

Clarification Statements:

- Explanations should be based on three variables in collision theory: (a) quantity of collisions per unit time, (b) molecular orientation on collision, and (c) energy input needed to induce atomic rearrangements.
- Conditions that affect these three variables include temperature, pressure, concentrations of reactants, agitation, particle size, surface area, and addition of a catalyst.

State Assessment Boundary:

- State assessment will be limited to simple reactions in which there are only two reactants and to specifying the change in only one variable at a time.

HS-PS1-6. Design ways to control the extent of a reaction at equilibrium (relative amount of products to reactants) by altering various conditions using Le Chatelier's principle. Make arguments based on kinetic molecular theory to account for how altering conditions would affect the forward and reverse rates of the reaction until a new equilibrium is established.*

Clarification Statements:

- Conditions that can be altered to affect the extent of a reaction include temperature, pressure, and concentrations of reactants.
- Conditions that can be altered to affect the rates of a reaction include temperature, pressure, concentrations of reactants, agitation, particle size, surface area, and addition of a catalyst.

State Assessment Boundaries:

- Calculations of equilibrium constants or concentrations are not expected in state assessment.
- State assessment will be limited to simple reactions in which there are only two reactants and to specifying the change in only one variable at a time.

HS-PS1-7. Use mathematical representations and provide experimental evidence to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. Use the mole concept and proportional relationships to evaluate the quantities (masses or moles) of specific reactants needed in order to obtain a specific amount of product.

Clarification Statements:

- Mathematical representations include balanced chemical equations that represent the laws of conservation of mass and constant composition (definite proportions), mass-to-mass stoichiometry, and calculations of percent yield.
- Evaluations may involve mass-to-mass stoichiometry and atom economy comparisons, but only for single-step reactions that do not involve complexes.

HS-PS1-9(MA). Relate the strength of an aqueous acidic or basic solution to the extent of an acid or base reacting with water as measured by the hydronium ion concentration (pH) of the solution. Make arguments about the relative strengths of two acids or bases with similar structure and composition.

Clarification Statements:

- Reactions are limited to Arrhenius and Bronsted-Lowry acid-base reaction patterns with monoprotic acids.
- Comparisons of relative strengths of aqueous acid or base solutions made from similar acid or base substances is limited to arguments based on periodic properties of elements, the electronegativity model of electron distribution, empirical dipole moments, and molecular geometry. Acid or base strength

comparisons are limited to homologous series and should include dilution and evaporation of water.

HS-PS1-10(MA). Use an oxidation-reduction reaction model to predict products of reactions given the reactants, and to communicate the reaction models using a representation that shows electron transfer (redox). Use oxidation numbers to account for how electrons are redistributed in redox processes used in devices that generate electricity or systems that prevent corrosion.*

Clarification Statement:

- Reactions are limited to simple oxidation-reduction reactions that do not require hydronium or hydroxide ions to balance half-reactions.

HS-PS1-11(MA). Design strategies to identify and separate the components of a mixture based on relevant chemical and physical properties.

Clarification Statements:

- Emphasis is on compositional and structural features of components of the mixture.
- Strategies can include chromatography, distillation, centrifuging, and precipitation reactions.
- Relevant chemical and physical properties can include melting point, boiling point, conductivity, and density.

[HS-PS1-8 is found in introductory physics.]

PS2. Motion and Stability: Forces and Interactions

HS-PS2-6. Communicate scientific and technical information about the molecular-level structures of polymers, ionic compounds, acids and bases, and metals to justify why these are useful in the functioning of designed materials.*

Clarification Statement:

- Examples could include comparing molecules with simple molecular geometries; analyzing how pharmaceuticals are designed to interact with specific receptors; and considering why electrically conductive materials are often made of metal, household cleaning products often contain ionic compounds to make materials soluble in water, or materials that need to be flexible but durable are made up of polymers.

State Assessment Boundary:

- State assessment will be limited to comparing substances of the same type with one compositional or structural feature different.

HS-PS2-7(MA). Construct a model to explain how ions dissolve in polar solvents (particularly water). Analyze and compare solubility and conductivity data to determine the extent to which different ionic species dissolve.

Clarification Statement:

- Data for comparison should include different concentrations of solutions with the same ionic species, and similar ionic species dissolved in the same amount of water.

HS-PS2-8(MA). Use kinetic molecular theory to compare the strengths of electrostatic forces and the prevalence of interactions that occur between molecules in solids, liquids, and gases. Use the combined gas law to determine changes in pressure, volume, and temperature in gases.

[HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4, HS-PS2-5, HS-PS2-9(MA), and HS-PS2-10(MA) are found in introductory physics.]

PS3. Energy

HS-PS3-4b. Provide evidence from informational text or available data to illustrate that the transfer of energy during a chemical reaction in a closed system involves changes in energy dispersal (enthalpy change) and heat content (entropy change) while assuming the overall energy in the system is conserved.

State Assessment Boundary:

- Calculations involving Gibbs free energy are not expected in state assessment.

[HS-PS3-1, HS-PS3-2, HS-PS3-3, HS-PS3-4a, and HS-PS3-5 are found in introductory physics.]

High School Introductory Physics

The high school introductory physics standards build from middle school and allow grade 9 or 10 students to explain additional and more complex phenomena central to the physical world. The standards expect students to apply a variety of science and engineering practices to three core ideas of physics:

- Standards on **motion and stability: forces and interactions** support students' understanding of ideas related to why some objects move in certain ways, why objects change their motion, and why some materials are attracted to each other while others are not. This core idea helps students answer the question, "How can one explain and predict interactions between objects and within systems of objects?" Students are able to demonstrate their understanding by applying scientific and engineering ideas related to Newton's second law, total momentum, conservation, system analysis, and gravitational and electrostatic forces.
- A focus on **energy** develops students' understanding of energy at both the macroscopic and atomic scales that can be accounted for as either motions of particles or energy stored in fields. This core idea helps students answer the question, "How is energy transferred and conserved?" Energy is understood as a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system; the total change of energy in any system is always equal to the total energy transferred into or out of the system. Students apply their understanding to explain situations that involve conservation of energy, energy transfer, and tracing the relationship between energy and forces.
- Standards on **waves and their applications in technologies for information transfer** support students' understanding of the physical principles used in a wide variety of existing and emerging technologies. As such, this core idea helps students answer the question, "How are waves used to transfer energy and send and store information?" Students are able to apply understanding of how wave properties and the interactions of electromagnetic radiation with matter can transfer information across long distances, store information, and investigate nature on many scales. They develop and use models of electromagnetic radiation, as either a wave of changing electric and magnetic fields or as particles. Students understand that combining waves of different frequencies can make a wide variety of patterns and thereby encode and transmit information. They can demonstrate their understanding by explaining how the principles of wave behavior and wave interactions with matter are used in technological devices to transmit and capture information and energy.

Across the set of high school introductory physics standards, particular emphasis is placed on **science and engineering practices** of developing and using models, analyzing and interpreting data, using mathematics, and engaging in argument from evidence. Students are expected to use mathematical and graphical representations and models to quantitatively and qualitatively describe, evaluate, and make predictions of a variety of phenomena such as motion, energy, and waves. Students should be able to use multiple types of models and compare their merits and limitations and level of detail and accuracy, and use them as a basis for explanations or arguments about underlying concepts or processes. The standards call for students to critique competing ideas and evaluate design solutions using data and evidence relevant to high school science. Analyzing and interpreting data gathered during investigations or experiments, such as of magnetic fields and electric current, wave properties, or motion, also contributes to students' development of explanations and arguments using relevant, quantitative evidence. Applying these practices across the core ideas gives students a rich grounding in introductory physics.

PS1. Matter and Its Interactions

HS-PS1-8. Develop a model to illustrate the energy released or absorbed during the processes of fission, fusion, and radioactive decay.

Clarification Statements:

- Examples of models include simple qualitative models, such as pictures or diagrams.
- Types of radioactive decay include alpha, beta, and gamma.

State Assessment Boundary:

- Quantitative calculations of energy released or absorbed are not expected in state assessment.

[HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS1-4, HS-PS1-5, HS-PS1-6, and HS-PS1-7 are found in chemistry.]

PS2. Motion and Stability: Forces and Interactions

HS-PS2-1. Analyze data to support the claim that Newton's second law of motion is a mathematical model describing change in motion (the acceleration) of objects when acted on by a net force.

Clarification Statements:

- Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, and a moving object being pulled by a constant force.
- Forces can include contact forces, including friction, and forces acting at a distance, such as gravity and magnetic forces.

State Assessment Boundary:

- Variable forces are not expected in state assessment.

HS-PS2-2. Use mathematical representations to show that the total momentum of a system of interacting objects is conserved when there is no net force on the system.

Clarification Statement:

- Emphasis is on the qualitative meaning of the conservation of momentum and the quantitative understanding of the conservation of linear momentum in interactions involving elastic and inelastic collisions between two objects in one dimension.

HS-PS2-3. Apply scientific principles of motion and momentum to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*

Clarification Statement:

- Both qualitative evaluations and algebraic manipulations may be used.

HS-PS2-4. Use mathematical representations of Newton's law of gravitation and Coulomb's law to both qualitatively and quantitatively describe and predict the effects of gravitational and electrostatic forces between objects.

Clarification Statement:

- Emphasis is on the relative changes when distance, mass or charge, or both are changed.

State Assessment Boundaries:

- State assessment will be limited to systems with two objects.
- Permittivity of free space is not expected in state assessment.

HS-PS2-5. Provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

Clarification Statement:

- Examples of evidence can include movement of a magnetic compass when placed in the vicinity of a current-carrying wire, and a magnet passing through a coil that turns on the light of a Faraday flashlight.

State Assessment Boundary:

- Explanations of motors or generators are not expected in state assessment.

HS-PS2-9(MA). Evaluate simple series and parallel circuits to predict changes to voltage, current, or resistance when simple changes are made to a circuit.

Clarification Statements:

- Predictions of changes can be represented numerically, graphically, or algebraically using Ohm's law.
- Simple changes to a circuit may include adding a component, changing the resistance of a load, and adding a parallel path, in circuits with batteries and common loads.
- Simple circuits can be represented in schematic diagrams.

State Assessment Boundary:

- Use of measurement devices and predictions of changes in power are not expected in state assessment.

HS-PS2-10(MA). Use free-body force diagrams, algebraic expressions, and Newton's laws of motion to predict changes to velocity and acceleration for an object moving in one dimension in various situations.

Clarification Statements:

- Predictions of changes in motion can be made numerically, graphically, and algebraically using basic equations for velocity, constant acceleration, and Newton's first and second laws.
- Forces can include contact forces, including friction, and forces acting at a distance, such as gravity and magnetic forces.

[HS-PS2-6, HS-PS2-7(MA), and HS-PS2-8(MA) are found in chemistry.]

PS3. Energy

HS-PS3-1. Use algebraic expressions and the principle of energy conservation to calculate the change in energy of one component of a system when the change in energy of the other component(s) of the system, as well as the total energy of the system including any energy entering or leaving the system, is known. Identify any transformations from one form of energy to another, including thermal, kinetic, gravitational, magnetic, or electrical energy, in the system.

Clarification Statement:

- Systems should be limited to two or three components and to thermal energy; kinetic energy; or the energies in gravitational, magnetic, or electric fields.

HS-PS3-2. Develop and use a model to illustrate that energy at the macroscopic scale can be accounted for as either motions of particles and objects or energy stored in fields.

Clarification Statements:

- Examples of phenomena at the macroscopic scale could include evaporation and condensation, the conversion of kinetic energy to thermal energy, the gravitational potential energy stored due to position of an object above the earth, and the stored energy (electrical potential) of a charged object's position within an electrical field.

- Examples of models could include diagrams, drawings, descriptions, and computer simulations.

HS-PS3-3. Design and evaluate a device that works within given constraints to convert one form of energy into another form of energy.*

Clarification Statements:

- Emphasis is on both qualitative and quantitative evaluations of devices.
- Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators.
- Examples of constraints could include use of renewable energy forms and efficiency.

State Assessment Boundary:

- Quantitative evaluations will be limited to total output for a given input in state assessment.

HS-PS3-4a. Provide evidence that when two objects of different temperature are in thermal contact within a closed system, the transfer of thermal energy from higher-temperature objects to lower-temperature objects results in thermal equilibrium, or a more uniform energy distribution among the objects and that temperature changes necessary to achieve thermal equilibrium depend on the specific heat values of the two substances.

Clarification Statement:

- Energy changes should be described both quantitatively in a single phase ($Q = mc\Delta T$) and conceptually either in a single phase or during a phase change.

HS-PS3-5. Develop and use a model of magnetic or electric fields to illustrate the forces and changes in energy between two magnetically or electrically charged objects changing relative position in a magnetic or electric field, respectively.

Clarification Statements:

- Emphasis is on the change in force and energy as objects move relative to each other.
- Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.

[HS-PS3-4b is found in chemistry.]

PS4. Waves and Their Applications in Technologies for Information Transfer

HS-PS4-1. Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling within various media. Recognize that electromagnetic waves can travel through empty space (without a medium) as compared to mechanical waves that require a medium.

Clarification Statements:

- Emphasis is on relationships when waves travel within a medium, and comparisons when a wave travels in different media.
- Examples of situations to consider could include electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, and seismic waves traveling through the Earth.
- Relationships include $v = \lambda f$, $T = 1/f$, and the qualitative comparison of the speed of a transverse (including electromagnetic) or longitudinal mechanical wave in a solid, liquid, gas, or vacuum.

State Assessment Boundary:

- Transitions between two media are not expected in state assessment.

HS-PS4-3. Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described by either a wave model or a particle model, and that for some situations involving resonance, interference, diffraction, refraction, or the photoelectric effect, one model is more useful than the other.

Clarification Statement:

- Emphasis is on qualitative reasoning and comparisons of the two models.

State Assessment Boundary:

- Calculations of energy levels or resonant frequencies are not expected in state assessment.

HS-PS4-5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.*

Clarification Statements:

- Emphasis is on qualitative information and descriptions.
- Examples of technological devices could include solar cells capturing light and converting it to electricity, medical imaging, and communications technology.
- Examples of principles of wave behavior include resonance, photoelectric effect, and constructive and destructive interference.

State Assessment Boundary:

- Band theory is not expected in state assessment.

[HS-PS4-2 and HS-PS4-4 from NGSS are not included.]

High School Technology/Engineering

The high school technology/engineering standards build from middle school and allow grade 9 or 10 students to explain major technological systems used in society and to engage in more sophisticated design problems. The standards expect students to apply a variety of science and engineering practices to four core ideas of technology/engineering:

- **Engineering design** standards support students' understanding of how engineering design is applied to complex societal challenges as well as developing their skills in defining design problems and developing solutions.
- A focus on **materials, tools, and manufacturing** supports students in understanding how manufacturing makes use of and can change material properties to create useful products. They consider different manufacturing processes, including where computer-aided systems can be useful, and how those processes can affect material properties.
- Standards about **technological systems** help students to learn how complex design systems work, particularly those they use every day. Such systems include communications systems, structural systems, and transportation systems. Through the study of these critical infrastructure systems, students understand how the components they interact with every day depend on the design and functioning of the larger system. They also can abstract the concept of a system, identifying inputs and outputs of subsystems and their interrelationships.
- **Energy and power technologies** standards support students in understanding how humans manipulate and use energy to accomplish physical tasks that would otherwise be impossible or difficult. These technologies include open and closed pneumatic and hydraulic systems.

The high school technology/engineering standards place particular emphasis on **science and engineering practices** of developing and using models; analyzing and interpreting data; using mathematics; designing solutions; and obtaining, evaluating, and communicating information. Relevant examples give students a valuable context to learn about and model a technological system, use a model to explain differences in systems or illustrate how a system works. This leads to a more detailed understanding of the role that engineering design, materials, tools, and manufacturing have in the natural and designed world. The standards expect students to research and analyze specific design solutions that give them an opportunity to determine optimal conditions for performance of materials, influences of cost, constraints, criteria, and possible environmental impacts. Use of mathematics is a key skill in designing prototypes to scale, using prototypes or simulations that model multiple interactions in a complex problem and calculating change to a system that includes a number of variables. Students communicate and evaluate solutions to real-world problems, propose or refine solutions, and examine the social and cultural impacts a product, material, manufacturing process, or technology could have in our world. The application of these practices across the core ideas gives students a rich grounding in technology/engineering.

ETS1. Engineering Design

HS-ETS1-1. Analyze a major global challenge to specify a design problem that can be improved. Determine necessary qualitative and quantitative criteria and constraints for solutions, including any requirements set by society.*

Clarification Statement:

- Examples of societal requirements can include risk mitigation, aesthetics, ethical considerations, and long-term maintenance costs.

HS-ETS1-2. Break a complex real-world problem into smaller, more manageable problems that each can be solved using scientific and engineering principles.*

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, aesthetics, and maintenance, as well as social, cultural, and environmental impacts.*

HS-ETS1-4. Use a computer simulation to model the impact of a proposed solution to a complex real-world problem that has numerous criteria and constraints on the interactions within and between systems relevant to the problem.*

HS-ETS1-5(MA). Plan a prototype or design solution using orthographic projections and isometric drawings, using proper scales and proportions.*

HS-ETS1-6(MA). Document and present solutions that include specifications, performance results, successes and remaining issues, and limitations.*

ETS2. Materials, Tools, and Manufacturing

HS-ETS2-1(MA). Determine the best application of manufacturing processes to create parts of desired shape, size, and finish based on available resources and safety.

Clarification Statement:

- Examples of processes can include forming (molding of plastics, casting of metals, shaping, rolling, forging, and stamping), machining (cutting and milling), conditioning (thermal, mechanical, and chemical processes), and finishing.

State Assessment Boundary:

- Specific manufacturing machines are not expected in state assessment.

HS-ETS2-2(MA). Explain how computers and robots can be used at different stages of a manufacturing system, typically for jobs that are repetitive, very small, or very dangerous.

Clarification Statement:

- Examples of stages include design, testing, production, and quality control.

HS-ETS2-3(MA). Compare the costs and benefits of custom versus mass production based on qualities of the desired product, the cost of each unit to produce, and the number of units needed.

HS-ETS2-4(MA). Explain how manufacturing processes transform material properties to meet a specified purpose or function. Recognize that new materials can be synthesized through chemical and physical processes that are designed to manipulate material properties to meet a desired performance condition.

Clarification Statement:

- Examples of material properties can include resistance to force, density, hardness, and elasticity.

ETS3. Technological Systems

HS-ETS3-1(MA). Model a technological system in which the output of one subsystem becomes the input to other subsystems.

HS-ETS3-2(MA). Use a model to explain how information transmitted via digital and analog signals travels through the following media: electrical wire, optical fiber, air, and space. Analyze a communication problem and determine the best mode of delivery for the communication(s).

HS-ETS3-3(MA). Explain the importance of considering both live loads and dead loads when constructing structures. Calculate the resultant force(s) for a combination of live loads and dead loads for various situations.

Clarification Statements:

- Examples of structures can include buildings, decks, and bridges.
- Examples of loads and forces include live load, dead load, total load, tension, sheer, compression, and torsion.

HS-ETS3-4(MA). Use a model to illustrate how the forces of tension, compression, torsion, and shear affect the performance of a structure. Analyze situations that involve these forces and justify the selection of materials for the given situation based on their properties.

Clarification Statements:

- Examples of structures include bridges, houses, and skyscrapers.
- Examples of material properties can include elasticity, plasticity, thermal conductivity, density, and resistance to force.

HS-ETS3-5(MA). Analyze how the design of a building is influenced by thermal conditions such as wind, solar angle, and temperature. Give examples of how conduction, convection, and radiation are considered in the selection of materials for buildings and in the design of a heating system.

HS-ETS3-6(MA). Use informational text to illustrate how a vehicle or device can be modified to produce a change in lift, drag, friction, thrust, and weight.

Clarification Statements:

- Examples of vehicles can include cars, boats, airplanes, and rockets.
- Considerations of lift require consideration of Bernoulli's principle.

ETS4. Energy and Power Technologies

HS-ETS4-1(MA). Research and describe various ways that humans use energy and power systems to harness resources to accomplish tasks effectively and efficiently.

Clarification Statement:

- Examples of energy and power systems can include fluid systems such as hydraulics and pneumatics, thermal systems such as heating and cooling, and electrical systems such as electronic devices and residential wiring.

HS-ETS4-2(MA). Use a model to explain differences between open fluid systems and closed fluid systems. Determine when it is more or less appropriate to use one type of system instead of the other.

Clarification Statements:

- Examples of open systems can include irrigation, forced hot air systems, and air compressors.
- Examples of closed systems can include forced hot water systems and hydraulic brakes.

HS-ETS4-3(MA). Explain how differences and similarities between hydraulic and pneumatic systems lead to different applications of each in technologies.

HS-ETS4-4(MA). Calculate and describe the ability of a hydraulic system to multiply distance, multiply force, and effect directional change.

Clarification Statement:

- Emphasis is on the ratio of piston sizes (cross-sectional area) as represented in Pascal's law.

HS-ETS4-5(MA). Explain how a machine converts energy, through mechanical means, to do work. Collect and analyze data to determine the efficiency of simple and complex machines.

Standards-Related Appendices

Appendix I
Science and Engineering Practices Progression Matrix

The Science and Engineering Practices

Science and engineering practices include the skills necessary to engage in scientific inquiry and engineering design. It is necessary to teach these so students develop an understanding and facility with the practices in appropriate contexts. The *Framework for K-12 Science Education* (NRC, 2012) identifies eight essential science and engineering practices:

1. Asking questions (for science) and defining problems (for engineering).
2. Developing and using models.
3. Planning and carrying out investigations.
4. Analyzing and interpreting data.
5. Using mathematics and computational thinking.
6. Constructing explanations (for science) and designing solutions (for engineering).
7. Engaging in argument from evidence.
8. Obtaining, evaluating, and communicating information.

The field of science education refers to these as "practices" rather than "science processes" or "inquiry skills" for several reasons. First, skills are not separate from concepts:

> We use the term "practices" instead of a term such as "skills" to emphasize that engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice.
>
> NRC, 2012, p. 30

Including discussion of the practices in this section does not suggest that education should separate the science and engineering practices from disciplinary core ideas. Students cannot fully appreciate the nature of scientific knowledge without engaging with the science and engineering practices.

Second, science and engineering are dynamic:

> Second, a focus on practices (in the plural) avoids the mistaken impression that there is one distinctive approach common to all science—a single "scientific method"—or that uncertainty is a universal attribute of science. In reality, practicing scientists employ a broad spectrum of methods, and although science involves many areas of uncertainty as knowledge is developed, there are now many aspects of scientific knowledge that are so well established as to be unquestioned foundations of the culture and its technologies. It is only through engagement in the practices that students can recognize how such knowledge comes about and why some parts of scientific theory are more firmly established than others.
>
> NRC, 2012, p. 44

Finally, the term "practices" is also used in standards instead of "inquiry" or "skills" to emphasize that the practices are outcomes to be learned, not a method of instruction. The term "inquiry" has been used in both contexts for so long that many educators do not separate the two uses. So the term "practices" denotes the expected outcomes (development of skills) that result from instruction, whether instruction is inquiry-based or not.

Rationale

Chapter 3 of the NRC *Framework* describes each of the eight practices of science and engineering and presents the following rationale for why they are essential:

> Engaging in the practices of science helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the wide range of approaches that are used to investigate, model, and explain the world. Engaging in the practices of engineering likewise helps students understand the work of engineers, as well as the links between engineering and science. Participation in these practices also helps students form an understanding of the crosscutting concepts and disciplinary ideas of science and engineering; moreover, it makes students' knowledge more meaningful and embeds it more deeply into their worldview.[*]
>
> The actual doing of science or engineering can also pique students' curiosity, capture their interest, and motivate their continued study; the insights thus gained help them recognize that the work of scientists and engineers is a creative endeavor—one that has deeply affected the world they live in. Students may then recognize that science and engineering can contribute to meeting many of the major challenges that confront society today, such as generating sufficient energy, preventing and treating disease, maintaining supplies of fresh water and food, and addressing climate change.
>
> Any education that focuses predominantly on the detailed products of scientific labor—the facts of science—without developing an understanding of how those facts were established or that ignores the many important applications of science in the world misrepresents science and marginalizes the importance of engineering.
>
> NRC, 2012, pp. 42–43

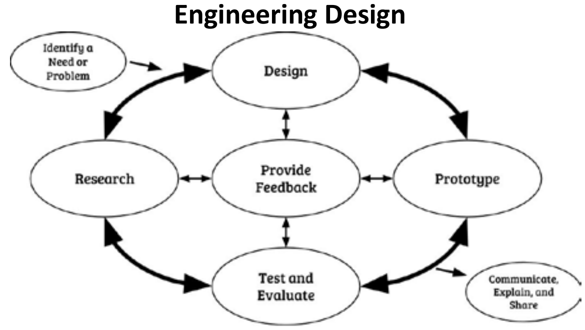
This appendix describes what students should be able to do relative to each of these eight practices. The charts presented in landscape format below are the "practices matrix": the specific capabilities that should be included in each practice for each grade span.

Scientific Inquiry and Engineering Design as Holistic and Dynamic Processes

Scientific inquiry and engineering design are dynamic and complex processes. Each requires engaging in a range of science and engineering practices to analyze and understand the natural and designed world. They are not defined by a linear, step-by-step approach. While students may learn and engage in distinct practices through their education, they should have periodic opportunities at each grade level to experience the holistic and dynamic processes represented below and described in the subsequent two pages.

Scientific Inquiry

Engineering Design



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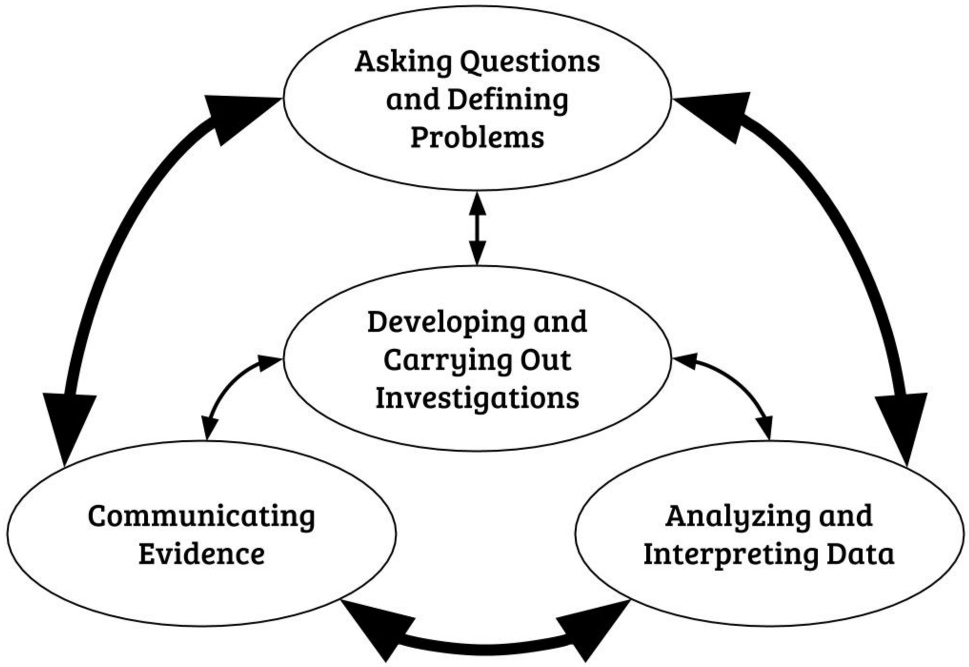
[*] See Appendix VIII for more on crosscutting concepts.

Scientific Inquiry



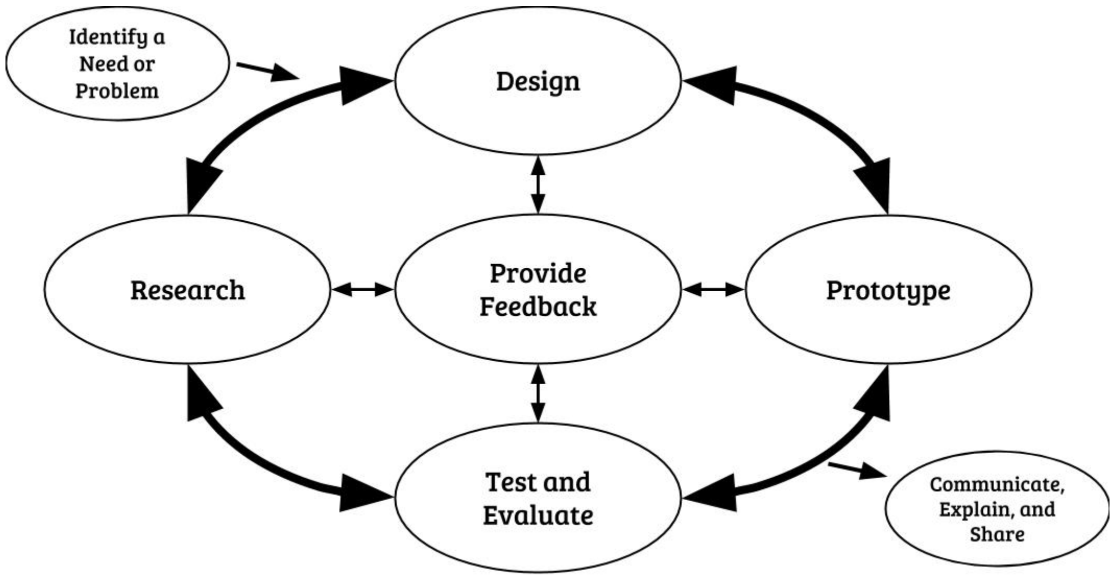
Asking questions and defining problems. Scientific questions arise in a variety of ways. They can be driven by curiosity about the world; inspired by the predictions of a model, theory, or findings from previous investigations; or stimulated by the need to solve a problem. Asking questions also leads to involvement in other practices.

Developing and carrying out investigations. Scientific investigations may be undertaken to describe a phenomenon, or to test a theory or model. It is important to state the goal of an investigation, predict outcomes, and plan a course of action that generates data to support claims in laboratory or field experiences. Variables must be identified as dependent or independent and intentionally varied from trial to trial or controlled across trials. Field investigations involve deciding how to collect different samples of data under different conditions, even though not all conditions are under the direct control of the investigator. Planning and carrying out investigations likely includes elements of other practices.

Analyzing and interpreting data. Analyzing data involves identifying significant features and patterns, using mathematics to represent relationships between variables, and considering sources of error. Computational thinking is central, involving strategies for organizing and searching data, creating sequences of steps, and using and developing simulations or models.

Communicating evidence. Communicating explanations for the causes of phenomena is central to science. An explanation includes a claim that relates how a variable or variables relate to another variable or set of variables. A claim is often made in response to a question and in the process of answering the question. Argumentation is a process for reaching agreements about explanations and design solutions. Reasoning based on evidence is essential in identifying the best explanation for a natural phenomenon. Being able to communicate clearly and persuasively is critical to engaging with multiple sources of technical information and evaluating the merit and validity of claims, methods, and designs.

Engineering Design



Identify a need or a problem. To begin engineering design, a need or problem must be identified that an attempt can be made to solve, improve and/or fix. This typically includes articulation of criteria and constraints that will define a successful solution.

Research. Research is done to learn more about the identified need or problem and potential solution strategies. Research can include primary resources such as research websites, peer-reviewed journals, and other academic services, and can be an ongoing part of design.

Design. All gathered information is used to inform the creations of designs. Design includes modeling possible solutions, refining models, and choosing the model(s) that best meets the original need or problem.

Prototype. A prototype is constructed based on the design model(s) and used to test the proposed solution. A prototype can be a physical, computer, mathematical, or conceptual instantiation of the model that can be manipulated and tested.

Test and evaluate. The feasibility and efficiency of the prototype must be tested and evaluated relative to the problem criteria and constraints. This includes the development of a method of testing and a system of evaluating the prototype's performance. Evaluation includes drawing on mathematical and scientific concepts, brainstorming possible solutions, testing and critiquing models, and refining the need or problem.

Provide feedback. Feedback through oral or written comments provides constructive criticism to improve a solution and design. Feedback can be asked for and/or given at any point during engineering design. Determining how to communicate and act on feedback is critical.

Communicate, explain, and share. Communicating, explaining, and sharing the solution and design is essential to conveying how it works and does (or does not), solving the identified need or problem, and meeting the criteria and constraints. Communication of explanations must be clear and analytical.

Assumptions for Science and Engineering Practices

The following assumptions guided the articulation and integration of the science and engineering practices into the standards:

- **Practices give students the skills necessary to engage in analytical thinking.** Students must be able to use their knowledge and skills to analyze and understand scientific phenomena, designed systems, and real-world problems to successfully contribute to civic society and the economy. The science and engineering practices articulate the skills that are needed to achieve this.
- **Students in grades pre-K–12 should engage in all eight practices over each grade span.** All eight practices are accessible at some level to all children of every age. The matrix identifies only the capabilities students should acquire by the end of each grade span. Importantly, science and engineering practices should be generalizable across core ideas and particular concepts. Curriculum developers and educators determine the strategies that advance students' abilities to use the practices.
- **Practices grow in complexity and sophistication across the grades.** Students' abilities to use the practices grow over time. The NRC *Framework* suggests how students' capabilities to use each of the practices should progress as they mature and engage in STE learning. While these progressions are derived from Chapter 3 of the NRC *Framework*, they are refined based on experiences in crafting the standards.
- **Each practice may reflect science or engineering.** Each of the eight practices can be used in the service of scientific inquiry and engineering design. One way to determine if a practice is being used for science or engineering is to ask about the goal of the activity. Is the goal to answer a question about natural phenomena? If so, students are likely engaged in science. Is the purpose to define and solve a problem to meet the needs of people? If so, students are likely engaged in engineering.
- **Practices represent what students are expected to do; they do not represent teaching methods or a curriculum.** The goal of standards is to describe what students should be able to do, rather than how they should be taught. The science and engineering practices are skills to be learned as a result of instruction; they do not define activities.
- **The eight practices are not separate; they intentionally overlap and interconnect.** As explained by Bell et al. (2012), the eight practices do not operate in isolation. Rather, they tend to unfold sequentially, and even overlap. For example, the practice of "asking questions" may lead to the practice of "modeling" or "planning and carrying out an investigation," which in turn may lead to "analyzing and interpreting data." The practice of "mathematical and computational thinking" may include some aspects of "analyzing and interpreting data." Just as it is important for students to carry out each of the individual practices, it is important for them to see the connections among the eight practices.
- **Standards focus on some but not all skills associated with a practice.** The matrix identifies a number of particular skills for each practice, listing the components of each practice as a bulleted list within each grade span. Individual standards can include only one, or perhaps two, skills.
- **Engagement in practices is language intensive and requires students to participate in relevant experiences and scientific and technical discourse.** The practices offer rich opportunities and demands for language learning while advancing STE learning for all students (Lee et al., 2013).

Brief Description of Each Science and Engineering Practice

Each practice is described briefly below; for more information, see the NRC *Framework* (NRC, 2012). The practices matrix follows the descriptions.

Practice 1. Asking Questions and Defining Problems

Scientific questions arise in a variety of ways. They can be driven by curiosity about the world; inspired by the predictions of a model, a theory, or findings from previous investigations; or stimulated by the need to solve a problem. Scientific questions are distinguished from other types of questions in that the answers lie in explanations supported by empirical evidence, including evidence gathered by others or through investigation.

While science begins with questions, engineering begins with defining a problem to solve. However, engineering may also involve asking questions to define a problem, such as: What is the need or desire that underlies the problem? What are the criteria for a successful solution? Other questions arise when generating ideas, or testing possible solutions, such as: What are possible trade-offs? What evidence is necessary to determine which solution is best?

Asking questions and defining problems also involves asking questions about data, claims that are made, and proposed designs. It is important to realize that asking a question also leads to involvement in another practice. A student can ask a question about data that will lead to further analysis and interpretation. Or a student might ask a question that leads to planning and design, an investigation, or the refinement of a design.

Practice 2. Developing and Using Models

Models include diagrams, physical replicas, mathematical representations, analogies, and computer simulations. Although models do not correspond exactly to the real world, they bring certain features into focus while obscuring others. All models contain approximations and assumptions that limit the range of validity and predictive power, so it is important for students to recognize their limitations.

In science, models are used to represent a system (or parts of a system) under study, to aid in the development of questions and explanations, to generate data that can be used to make predictions, and to communicate ideas to others. Students can be expected to evaluate and refine models through an iterative cycle of comparing their predictions with the real world and then adjusting them to gain insights into the phenomenon being modeled. As such, models are based on evidence. When new evidence is uncovered that they cannot explain, models are modified.

In engineering, models may be used to analyze a system to see where or under what conditions flaws might develop, or to test possible solutions to a problem. They can also be used to visualize and refine a design or to communicate a design's features. Prototypes are physical or simulated instantiations of a model that can be manipulated and tested for specified variables, design features, or functions.

Practice 3. Planning and Carrying Out Investigations

Scientific investigations may be undertaken to describe a phenomenon, or to test a theory or model for how the world works. The purpose of engineering investigations might be to find out how to fix or improve the functioning of a technological system or to compare different solutions to see which best solves a problem. Whether students are doing science or engineering, it is always important for them to state the goal of an investigation, predict outcomes, and plan a course of action that will provide the best evidence to support their conclusions. Students should design investigations that generate data to provide evidence to support claims they make about phenomena. Data are not evidence until used in the process of supporting a claim. Students should use reasoning and scientific ideas, principles, and theories to show why data can be considered evidence.

Over time, students should become more systematic and careful in their methods. In laboratory experiments, students are expected to decide which variables should be treated as dependent or independent; which should be treated as inputs and intentionally varied from trial to trial; and which should be controlled, or kept the same across trials. In the case of field observations, planning involves deciding how to collect different samples of data under different conditions, even though not all conditions are under the direct control of the investigator. Planning and carrying out investigations may include elements of all of the other practices.

Practice 4. Analyzing and Interpreting Data

> Once collected, data must be presented in a form that can reveal any patterns and relationships and that allows results to be communicated to others. Because raw data as such have little meaning, a major practice of scientists is to organize and interpret data through tabulating, graphing, or statistical analysis. Such analysis can bring out the meaning of data—and their relevance—so that they may be used as evidence.
>
> Engineers, too, make decisions based on evidence that a given design will work; they rarely rely on trial and error. Engineers often analyze a design by creating a model or prototype and collecting extensive data on how it performs, including under extreme conditions. Analysis of this kind of data not only informs design decisions and enables the prediction or assessment of performance but also helps define or clarify problems, determine economic feasibility, evaluate alternatives, and investigate failures.
>
> NRC, 2012, pp. 61–62

As students mature, they expand their capabilities to use a range of tools for tabulation, graphical representation, visualization, and statistical analysis. Students also improve their ability to interpret data by identifying significant features and patterns, using mathematics to represent relationships between variables, and taking into account sources of error. When possible and feasible, students should use digital tools to analyze and interpret data. Students' analysis and interpretation of data result in evidence to support their conclusions.

Practice 5. Using Mathematics and Computational Thinking

Students are expected to use mathematics to represent physical variables and their relationships, and to make quantitative predictions. Other applications of mathematics in science and engineering include logic, geometry, and, at the highest levels, calculus. Computers and digital tools can enhance the power of mathematics by automating calculations, approximating solutions to problems that cannot be calculated precisely, and analyzing large data sets available to identify meaningful patterns. Students are expected to use laboratory tools connected to computers for observing, measuring, recording, visualizing, and processing data. Students are also expected to engage in computational thinking, which involves strategies for organizing and searching data, creating sequences of steps called algorithms, and using and developing new simulations of natural and designed systems. Mathematics is a tool that is key to understanding science.

Practice 6. Constructing Explanations and Designing Solutions

The goal of science is to construct explanations for the causes of phenomena. Students construct their own explanations, as well as apply standard explanations they learn about through instruction. The NRC *Framework* states the following about explanation:

> The goal of science is the construction of theories that provide explanatory accounts of the world. A theory becomes accepted when it has multiple lines of empirical evidence and greater explanatory power of phenomena than previous theories.
>
> NRC, 2012, p. 52

An explanation includes a claim that relates how a variable or variables relate to another variable or set of variables. A claim is often made in response to a question and in the process of answering the question, scientists often design investigations to generate data.

The goal of engineering is to systematically solve problems. Engineering design involves defining the problem, then generating, testing, and improving solutions. The NRC *Framework* describes this practice as follows.

> The process of developing a design is iterative and systematic, as is the process of developing an explanation or a theory in science. Engineers' activities, however, have elements that are distinct from those of scientists. These elements include specifying constraints and criteria for desired qualities of the solution, developing a design plan, producing and testing models or prototypes, selecting among alternative design features to optimize the achievement of design criteria, and refining design ideas based on the performance of a prototype or simulation.
>
> NRC, 2012, pp. 68–69

Practice 7. Engaging in Argument from Evidence

Argumentation is a process for reaching agreements about explanations and design solutions. In science, reasoning and argument based on evidence are essential in identifying the best explanation for a natural phenomenon. In engineering, reasoning and argument are needed to identify the best solution to a design problem. Student engagement in argumentation is critical if students are to understand the culture in which scientists and engineers live, and how to apply science and engineering for the benefit of society. As such, argument is a process based on evidence and reasoning that leads to explanations acceptable by the scientific community and design solutions acceptable by the engineering community.

Argument in science goes beyond reaching agreements in explanations and design solutions. Scientists and engineers engage in argumentation when investigating a phenomenon, testing a design solution, resolving questions about measurements, building data models, and using evidence to evaluate claims. Whether investigating a phenomenon, testing a design, or constructing a model to provide a mechanism for an explanation, students are expected to use argumentation to listen to, compare, and evaluate competing ideas and methods based on their merits.

Practice 8. Obtaining, Evaluating, and Communicating Information

Being able to read, interpret, and produce scientific and technical text is a fundamental practice of science and engineering, as is the ability to communicate clearly and persuasively. Being a critical consumer of information about science and engineering requires the ability to read or view reports of scientific or technological advances or applications (whether found in the press, on the Internet, or at a town meeting) and to recognize the salient ideas, identify sources of error and methodological flaws, distinguish observations from inferences, arguments from explanations, and claims from evidence. Scientists and engineers use multiple sources of information to evaluate the merit and validity of claims, methods, and designs. Communicating information, evidence, and ideas can be done in multiple ways: using tables, diagrams, graphs, models, interactive displays, and equations, as well as orally and in writing.

[This appendix draws from and is an adaptation of the NGSS, Appendix F.]

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Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
1. Asking Questions and Defining Problems A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world works and which can be empirically tested. Engineering questions clarify problems to determine criteria for successful solutions and identify constraints to solve problems about the designed world. Both scientists and engineers also ask questions to clarify ideas.	Asking questions and defining problems in pre-K–2 builds on prior experiences and progresses to simple descriptive questions that can be tested.	Asking questions and defining problems in 3–5 builds on pre-K–2 experiences and progresses to specifying qualitative relationships.	Asking questions and defining problems in 6–8 builds on pre-K–5 experiences and progresses to specifying relationships between variables, and clarifying arguments and models.	Asking questions and defining problems in 9–12 builds on pre-K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations.
	• Ask questions based on observations to find more information about the natural and/or designed worlds.	• Ask questions about what would happen if a variable is changed.	• Ask questions: o That arise from careful observation of phenomena, models, or unexpected results, to clarify and/or seek additional information. o To identify and/or clarify evidence and/or the premise(s) of an argument. o To determine relationships between independent and dependent variables and relationships in models. o To clarify and/or refine a model, an explanation, or an engineering problem.	• Ask questions: o That arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information. o That arise from examining models or a theory, to clarify and/or seek additional information and relationships. o To determine relationships, including quantitative relationships, between independent and dependent variables. o To clarify and refine a model, an explanation, or an engineering problem.

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
	• Ask and/or identify questions that can be answered by an investigation.	• Identify scientific (testable) and non-scientific (non-testable) questions. • Ask questions that can be investigated and predict reasonable outcomes based on patterns, such as cause and effect relationships.	• Ask questions that require sufficient and appropriate empirical evidence to answer. • Ask questions that can be investigated within the scope of the classroom, outdoor environment, and museums and other public facilities with available resources and, when appropriate, frame a hypothesis based on observations and scientific principles.	• Evaluate a question to determine if it is testable and relevant. • Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory.
			• Ask questions that challenge the premise(s) of an argument or the interpretation of a data set.	• Ask and/or evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design.
	• Define a simple problem that can be solved through the development of a new or improved object or tool.	• Use prior knowledge to describe problems that can be solved. • 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.	• 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.	• 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.

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
2. Developing and Using Models A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. Modeling tools are used to develop questions, predictions, and explanations; analyze and identify flaws in systems; and communicate ideas. Models are used to build and revise scientific explanations and proposed engineered systems. Measurements and observations are used	Modeling in pre-K–2 builds on prior experiences and progresses to include using and developing models (e.g., diagram, drawing, physical replica, diorama, dramatization, or storyboard) that represent concrete events or design solutions.	Modeling in 3–5 builds on pre-K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions.	Modeling in 6–8 builds on pre-K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.	Modeling in 9–12 builds on pre-K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.
	• Distinguish between a model and the actual object, process, and/or events the model represents. • Compare models to identify common features and differences.	• Identify limitations of models.	• Evaluate limitations of a model for a proposed object or tool.	• 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. • Design a test of a model to ascertain its reliability.
	• Develop and/or use a model to represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed worlds.	• Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequent and regular occurring events. • Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution.	• Develop or modify a model—based on evidence—to match what happens if a variable or component of a system is changed. • Use and/or develop a model of simple systems with uncertain and less predictable factors. • Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable	• 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. • 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.

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
to revise models and designs.		• Develop and/or use models to describe and/or predict phenomena.	phenomena. • Develop and/or use a model to predict and/or describe phenomena. • Develop a model to describe unobservable mechanisms.	
	• Develop a simple model based on evidence to represent a proposed object or tool.	• Develop a diagram or simple physical prototype to convey a proposed object, tool, or process. • Use a model to test cause and effect relationships or interactions concerning the functioning of a natural or designed system.	• 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.	• Develop a complex model that allows for manipulation and testing of a proposed process or system. • Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.

Science and Engineering Practices	**Pre-K–2 Condensed Practices**	**3–5 Condensed Practices**	**6–8 Condensed Practices**	**9–12 Condensed Practices**
3. Planning and Carrying Out Investigations Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters. Engineering investigations identify the effectiveness, efficiency, and durability of designs under different conditions.	Planning and carrying out investigations to answer questions or test solutions to problems in pre-K–2 builds on prior experiences and progresses to simple investigations, based on fair tests, which provide data to support explanations or design solutions.	Planning and carrying out investigations to answer questions or test solutions to problems in 3–5 builds on pre-K–2 experiences and progresses to include investigations that *control variables* and provide evidence to support explanations or design solutions.	Planning and carrying out investigations in 6–8 builds on pre-K–5 experiences and progresses to include investigations that use *multiple variables* and provide evidence to support explanations or solutions.	Planning and carrying out investigations in 9–12 builds on pre-K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.
	• With guidance, plan and conduct an investigation in collaboration with peers (for K). • Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence to answer a question.	• Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence, using fair tests in which variables are controlled and the number of trials considered.	• Plan an investigation individually and collaboratively, and in the design identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim. • Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation.	• 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 confounding variables or effects and evaluate the investigation's design to ensure that variables are controlled. • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design decide on the types, quantity, and accuracy of data needed to produce reliable measurements; consider limitations on the precision of the data (e.g., number of trials, cost, risk, time); and refine the design accordingly.

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
				• Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts.
	• Evaluate different ways of observing and/or measuring a phenomenon to determine which way to answer a question.	• Evaluate appropriate methods and/or tools for collecting data.	• Evaluate the accuracy of various methods for collecting data.	• Select appropriate tools to collect, record, analyze, and evaluate data.
	• Make observations (first-hand or from media) and/or measurements to collect data that can be used to make comparisons. • 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. • Make predictions based on prior experiences.	• 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. • Make predictions about what would happen if a variable changes. • Test two different models of the same proposed object, tool, or process to determine which better meets criteria for success.	• Collect data to serve as the basis for evidence to answer scientific questions or test design solutions under a range of conditions. • Collect data about the performance of a proposed object, tool, process, or system under a range of conditions.	• Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated. • 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.

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
4. Analyzing and Interpreting Data Scientific investigations produce data that must be analyzed in order to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data. Scientists identify sources of error in the investigations and calculate the degree of certainty in the results. Modern technology makes the collection of large data sets much easier, providing secondary sources for analysis. Engineering investigations include analysis of data collected in the tests of designs. This allows comparison of different solutions and determines how well each meets specific	Analyzing data in pre-K–2 builds on prior experiences and progresses to collecting, recording, and sharing observations.	Analyzing data in 3–5 builds on pre-K–2 experiences and progresses to introducing quantitative approaches to collecting data and conducting multiple trials of qualitative observations. When possible and feasible, digital tools should be used.	Analyzing data in 6–8 builds on pre-K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.	Analyzing data in 9–12 builds on pre-K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.
	• Record information (observations, thoughts, and ideas). • Use and share pictures, drawings, and/or writings of observations. • Use observations (first-hand or from media) to describe patterns and/or relationships in the natural and designed worlds in order to answer scientific questions and solve problems. • Compare predictions (based on prior experiences) to what occurred (observable events).	• Represent data in tables and/or various graphical displays (bar graphs, pictographs, and/or pie charts) to reveal patterns that indicate relationships.	• Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships. • Use graphical displays (e.g., maps, charts, graphs, and/or tables) of large data sets to identify temporal and spatial relationships. • Distinguish between causal and correlational relationships in data. • Analyze and interpret data to provide evidence for phenomena.	• 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.
		• Analyze and interpret data to make sense of phenomena, using logical reasoning, mathematics, and/or computation.	• Apply concepts of statistics and probability (including mean, median, mode, and variability) to analyze and characterize data, using digital tools when feasible.	• Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
design criteria—that is, which design best solves the problem within given constraints. Like scientists, engineers require a range of tools to identify patterns within data and interpret the results. Advances in science make analysis of proposed solutions more efficient and effective.				problems, using digital tools when feasible.
			• Consider limitations of data analysis (e.g., measurement error), and/or seek to improve precision and accuracy of data with better technological tools and methods (e.g., multiple trials).	• Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data.
		• Compare and contrast data collected by different groups in order to discuss similarities and differences in their findings.	• Analyze and interpret data to determine similarities and differences in findings.	• Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations.
	• Analyze data from tests of an object or tool to determine if it works as intended.	• Analyze data to refine a problem statement or the design of a proposed object, tool, or process. • Use data to evaluate and refine design solutions.	• Analyze data to define an optimal operational range for a proposed object, tool, process, or system that best meets criteria for success.	• Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. • 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.

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
5. Using Mathematics and Computational Thinking In both science and engineering, mathematics and computation are fundamental tools for representing physical variables and their relationships. They are used for a range of tasks such as constructing simulations; solving equations exactly or approximately; and recognizing, expressing, and applying quantitative relationships. Mathematical and computational approaches enable scientists and engineers to predict the behavior of systems and test the validity of such predictions.	Mathematical and computational thinking in pre-K–2 builds on prior experience and progresses to recognizing that mathematics can be used to describe the natural and designed worlds.	Mathematical and computational thinking in 3–5 builds on pre-K–2 experiences and progresses to extending quantitative measurements to a variety of physical properties and using computation and mathematics to analyze data and compare alternative design solutions.	Mathematical and computational thinking in 6–8 builds on pre-K–5 experiences and progresses to identifying patterns in large data sets and using mathematical concepts to support explanations and arguments.	Mathematical and computational thinking in 9–12 builds on pre-K–8 and experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.
	• Decide when to use qualitative versus quantitative data.	• Decide if qualitative or quantitative data are best to determine whether a proposed object or tool meets criteria for success.		
	• Use counting and numbers to identify and describe patterns in the natural and designed worlds.	• Organize simple data sets to reveal patterns that suggest relationships.	• Use digital tools (e.g., computers) to analyze very large data sets for patterns and trends.	• Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system.
	• Describe, measure, and/or compare quantitative attributes of different objects and display the data using simple graphs.	• Describe, measure, estimate, and/or graph quantities such as area, volume, weight, and time to address scientific and engineering questions and problems.	• Use mathematical representations to describe and/or support scientific conclusions and design solutions.	• Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.

	• Use quantitative data to compare two alternative solutions to a problem.	• Create and/or use graphs and/or charts generated from simple algorithms to compare alternative solutions to an engineering problem.	• Create algorithms (a series of ordered steps) to solve a problem. • Apply mathematical concepts and/or processes (such as ratio, rate, percent, basic operations, and simple algebra) to scientific and engineering questions and problems. • Use digital tools and/or mathematical concepts and arguments to test and compare proposed solutions to an engineering design problem.	• Apply techniques of algebra and functions to represent and solve scientific and engineering problems. • Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world. • Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m^3, acre-feet, etc.).

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
6. Constructing Explanations and Designing Solutions *The end-products of science are explanations and the end-products of engineering are solutions.* The goal of science is the construction of theories that provide explanatory accounts of the world. A theory becomes accepted when it has multiple lines of empirical evidence and greater explanatory power of phenomena than previous theories. The goal of engineering design is to find a systematic solution to problems that is based on scientific knowledge and models of the material world. Each proposed solution results from a process of balancing competing criteria of desired functions, technical feasibility, cost, safety, aesthetics, and compliance with legal requirements.	Constructing explanations and designing solutions in pre-K–2 builds on prior experiences and progresses to the use of evidence and ideas in constructing evidence-based accounts of natural phenomena and designing solutions.	Constructing explanations and designing solutions in 3–5 builds on pre-K–2 experiences and progresses to the use of evidence in constructing explanations that specify variables that describe and predict phenomena and in designing multiple solutions to design problems.	Constructing explanations and designing solutions in 6–8 builds on pre-K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.	Constructing explanations and designing solutions in 9–12 builds on pre-K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.
	• Use information from observations (first-hand and from media) to construct an evidence-based account for natural phenomena.	• Construct an explanation of observed relationships (e.g., the distribution of plants in the backyard).	• Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena. • Construct an explanation using models or representations.	• Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.
		• Use evidence (e.g., measurements, observations, patterns) to construct or support an explanation or design a solution to a problem.	• 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.	• 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.

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
The optimal choice depends on how well the proposed solutions meet criteria and constraints.			• Apply scientific ideas, principles, and/or evidence to construct, revise, and/or use an explanation for real-world phenomena, examples, or events.	• Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.
		• Identify the evidence that supports particular points in an explanation.	• Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion.	• Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.
	• Use tools and/or materials to design and/or build a device that solves a specific problem. • Generate and/or compare multiple solutions to a problem.	• Apply scientific ideas to solve design problems. • Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solution.	• Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process, or system. • Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints. • Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and re-testing.	• 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.

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
7. Engaging in Argument from Evidence *Argumentation is the process by which evidence-based conclusions and solutions are reached.* In science and engineering, reasoning and argument based on evidence are essential to identifying the best explanation for a natural phenomenon or the best solution to a design problem. Scientists and engineers use argumentation to listen to, compare, and evaluate competing ideas and methods based on merits. Scientists and engineers engage in argumentation when investigating a phenomenon, testing a design solution, resolving questions about measurements, building data models, and using evidence to evaluate claims.	Engaging in argument from evidence in pre-K–2 builds on prior experiences and progresses to comparing ideas and representations about the natural and designed worlds.	Engaging in argument from evidence in 3–5 builds on pre-K–2 experiences and progresses to critiquing the scientific explanations or solutions proposed by peers by citing relevant evidence about the natural and designed worlds.	Engaging in argument from evidence in 6–8 builds on pre-K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed worlds.	Engaging in argument from evidence in 9–12 builds on pre-K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed worlds. Arguments may also come from current scientific or historical episodes in science.
	• Identify arguments that are supported by evidence. • Distinguish between explanations that account for all gathered evidence and those that do not. • Analyze why some evidence is relevant to a scientific question and some is not. • Distinguish between opinions and evidence in one's own explanations.	• Compare and refine arguments based on an evaluation of the evidence presented. • Distinguish among facts, reasoned judgment based on research findings, and speculation in an explanation.	• Compare and critique two arguments on the same topic and analyze whether they emphasize similar or different evidence and/or interpretations of facts.	• Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues. • Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.
	• Listen actively to arguments to indicate agreement or disagreement based on evidence, and/or to retell the main points of the argument.	• Respectfully provide and receive critiques from peers about a proposed procedure, explanation, or model by citing relevant evidence and posing	• Respectfully provide and receive critiques about one's explanations, procedures, models, and questions by citing relevant evidence and posing and responding to questions	• Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence and challenging ideas and conclusions, responding thoughtfully to diverse

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
		specific questions.	that elicit pertinent elaboration and detail.	perspectives, and determining what additional information is required to resolve contradictions.
	• Construct an argument with evidence to support a claim.	• Construct and/or support an argument with evidence, data, and/or a model. • Use data to evaluate claims about cause and effect.	• Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.	• Construct, use, and/or present an oral and written argument or counterarguments based on data and evidence.
	• Make a claim about the effectiveness of an object, tool, or solution that is supported by relevant evidence.	• 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.	• Make an oral or written argument that supports or refutes the advertised performance of a device, process, or system, based on empirical evidence concerning whether or not the technology meets relevant criteria and constraints. • Evaluate competing design solutions based on jointly developed and agreed-upon design criteria.	• Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence. • Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and/or logical arguments regarding relevant factors (e.g., economic, societal, environmental, ethical considerations).

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
8. Obtaining, Evaluating, and Communicating Information Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity. Communicating information and ideas can be done in multiple ways: using tables, diagrams, graphs, models, and equations as well as orally and in writing. Scientists and engineers employ multiple sources to obtain information that is used to evaluate the merit and validity of claims, methods, and designs.	Obtaining, evaluating, and communicating information in pre-K–2 builds on prior experiences and uses observations and texts to communicate new information.	Obtaining, evaluating, and communicating information in 3–5 builds on pre-K–2 experiences and progresses to evaluating the merit and accuracy of ideas and methods.	Obtaining, evaluating, and communicating information in 6–8 builds on pre-K–5 experiences and progresses to evaluating the merit and validity of ideas and methods.	Obtaining, evaluating, and communicating information in 9–12 builds on pre-K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs.
	• Read grade-appropriate texts and/or use media to obtain scientific and/or technical information to determine patterns in and/or evidence about the natural and designed worlds.	• Read and comprehend grade-appropriate complex texts and/or other reliable media to summarize and obtain scientific and technical ideas and describe how they are supported by evidence. • Compare and/or combine complex texts and/or other reliable media to support an investigation or design.	• Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed worlds.	• Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
	• Describe how specific images (e.g., a diagram showing how a machine works) support a scientific or engineering idea.	• Combine information in written text with that contained in corresponding tables, diagrams, and/or charts to support an investigation or design.	• Integrate qualitative and/or quantitative scientific and/or technical information in written text with that contained in media and visual displays to clarify claims and findings.	• Compare, integrate, and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively), as well as in words in order to address a scientific question or solve a problem.

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
	• Obtain information using various texts, text features (e.g., headings, tables of contents, glossaries, electronic menus, icons), and other media that will be useful in answering a scientific question and/or supporting a scientific claim.	• Obtain and combine information from books and/or other reliable media to explain phenomena or solutions to a design problem.	• Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and set of methods used, and describe how they are supported or not supported by evidence. • Evaluate data, hypotheses, and/or conclusions in scientific and technical texts in light of competing information or accounts.	• Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source. • Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible.
	• 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.	• Communicate scientific and/or technical information orally and/or in written formats, including various forms of media as well as tables, diagrams, and charts.	• Communicate scientific and/or technical information (e.g., about a proposed object, tool, process, system) in writing and/or through oral presentations.	• Communicate scientific and/or technical information or ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).

Appendix II
Essential Role of Language, Literacy, and Mathematics for Science and Technology/Engineering Learning for All Students

When language, literacy, and mathematics are integrated with STE through rich, relevant, and experiential learning, all students are supported in developing understanding and facility with STE concepts and skills.

Language and Literacy

Language and Literacy to Support STE Learning for All Students

Literacy skills are critical to building and applying knowledge in STE. Students become proficient in reading, writing, listening, and speaking when they have a strong command of all three features of academic language: word/phrase (including general and domain-specific vocabulary), sentence, and discourse levels (WIDA, 2013; see chart on p. 18). Reading and writing in STE requires an appreciation of the norms and conventions of the discipline of science, including understanding the nature of evidence used, an attention to precision and detail, and the capacity to make and assess intricate arguments, synthesize complex information, and follow detailed procedures and accounts of events and concepts.

Each academic discipline presupposes specific kinds of background knowledge about text and discourse features, as well as strategies for reading disciplinary texts. STE teachers are best positioned to engage their students in disciplinary discourse as students experiment with using productive comprehension strategies to learn with specific academic disciplines (Buehl, 2011). STE teachers are immersed in academic language daily, and it is often hard to notice the skills we habitually draw on to understand disciplinary language. It is important to make linguistic choices explicit with students and become more aware of the complex ways in which disciplinary language affects STE learning.

Creating an intentionally inclusive classroom culture relies on skilled facilitation that offers rich, rigorous learning opportunities accessible for all learners. Effective engagement in any of the science and engineering practices involves making sense of science through application and discourse. This requires a contingent pedagogy that includes eliciting students' prior knowledge, providing relevant experiences to anchor discourse, and providing nuanced and flexible scaffolding that addresses a progression of learning STE content. Every student benefits from careful attention to language in STE instruction, including linguistically diverse students and students with disabilities.

Students also need to be able to gain knowledge from technical diagrams and mathematical data that convey information and illustrate STE concepts. Likewise, writing information and presenting it orally are key means for students to assert and defend claims in STE, demonstrate what they know about a concept, and convey what they have experienced, imagined, thought, and learned. Students benefit from discussion to clarify their thinking, build language proficiency, and prepare for writing about STE concepts.

Purposeful planning of conversations enhances science learning and academic performance when students have frequent opportunities to engage in collaboration and academic conversations with their peers (Michaels & O'Connor, 2012). These conversations may range from short questions and comments among students, as they investigate a phenomenon or problem, to more sustained discussions that include presenting evidence to support a claim, critiquing a solution, or evaluating a problem. They listen and process information as they present their ideas or engage in reasoned argumentation with others to refine their ideas, critique others, and reach shared conclusions. Students must also read, write, and visually represent ideas as they develop models and construct explanations. The requirements and norms for classroom discourse are shared across all the STE disciplines and, indeed, across all the subject areas.

All students stand to gain from effective STE instruction that involves experience with science and engineering practices. Teachers must carefully plan to scaffold, modify, facilitate, and support all students to access STE content and practices as well as language development. When supported appropriately, all students can learn, comprehend, and carry out sophisticated language functions[*] in STE contexts (e.g., arguing from evidence, providing explanations, developing models). For English language learners in particular, the focus is on the developmental nature of language and the careful use of instructional supports and scaffoldings so all students can participate in grade-level curricula and higher-order thinking. For students with disabilities, knowing what they need to be successful and providing differentiated ways for them to develop and communicate their understanding is essential.

Role of Vocabulary in STE Instruction

Students need to have a facility for using technical terms in order to effectively learn complex STE to communicate with others about their learning. In STE, vocabulary provides the labels used to represent a concept or process. A vocabulary-rich classroom encourages students to link their conceptual understanding with key scientific and technical terms. This promotes clearer and more efficient communication about the content and enables shared understanding. Science and engineering build knowledge over time through collaborative exchanges and peer review of new knowledge and processes. As a student's body of knowledge grows, their scientific and technical vocabulary should grow with it. Without strong literacy skills, including the understanding and use of scientific and technical vocabulary, students will have difficulty participating in STE endeavors or understanding scientific and technical texts, even texts that are written for a general audience.

The STE standards represent specific choices about which vocabulary to include and which to omit in defining learning outcomes. Where possible, a focus on the underlying scientific concept or process has been emphasized and lists of scientific and technical terms have been minimized. In a few instances, a state assessment boundary clarifies that certain terms will be excluded from state assessments. The omission of such terms from the standards or the state assessment, however, does not imply that students should not learn them. Educators should make deliberate choices about which scientific and technical vocabulary to have students learn and use in their studies and classroom discussions that can go beyond vocabulary used in the standards.

It is important to recognize that effective communication about STE includes more than vocabulary. Language is an integral part of learning STE: not only a tool for communication, but also a tool for scientific thinking and reasoning. Students learn to engage in scientific thinking and reasoning by making conjectures, presenting explanations, and constructing arguments, all of which require a shared vocabulary to achieve more.

[*] "Language function" refers to the purpose for a particular use of language (e.g., recount, explain, argue). It is what students *do* with language to accomplish content-specific tasks.

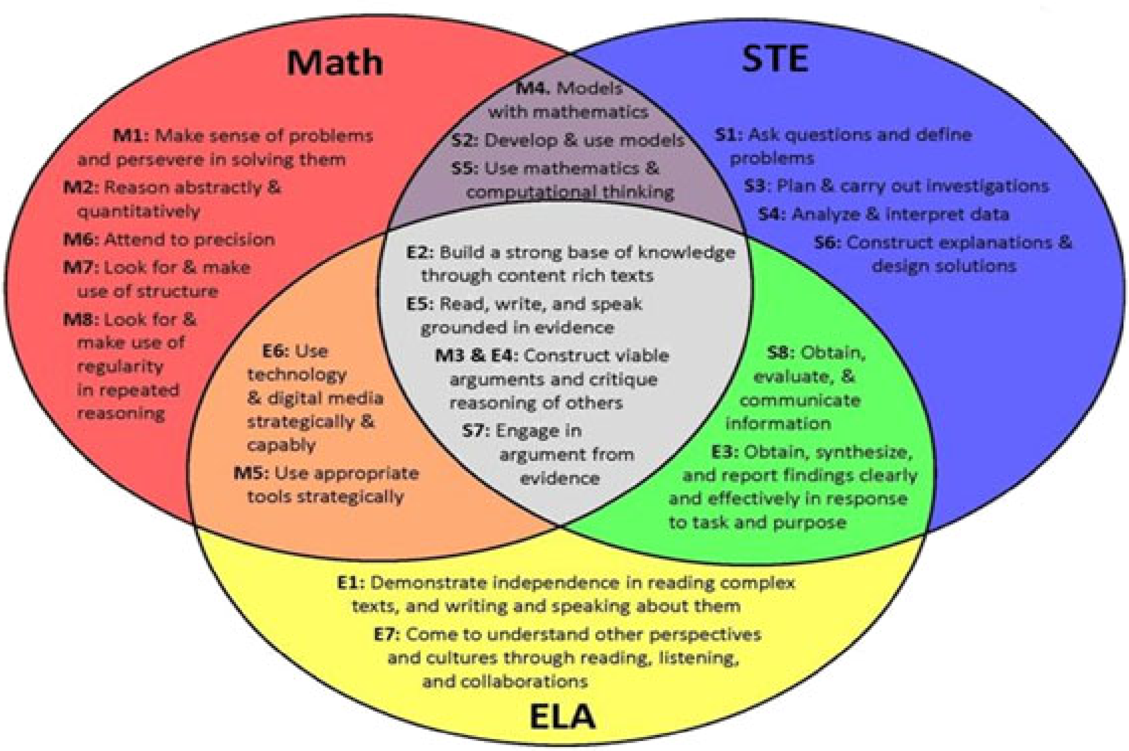
Mathematics

Mathematics is a language and a key tool used in STE. STE also provides an excellent context for learning and applying mathematics. Students use mathematics in STE to represent physical variables, describe relationships among variables, and make quantitative predictions. Computers and digital tools can enhance the power of mathematics by automating calculations, approximating solutions to problems that cannot be calculated precisely, and analyzing large data sets to identify meaningful patterns. Students use laboratory tools connected to computers for observing, measuring, recording, and processing data. Students also engage in computational thinking, which involves strategies for organizing and searching data, creating sequences of steps (algorithms), and using and developing new simulations of natural and designed systems.

Modeling is a particular area where STE and mathematics have significant overlap. Students develop and use models in their STE classes to describe the complex systems in our natural world, and then augment these models using mathematics. The descriptions, predictions, and analyses that such mathematical models yield can be rich and dynamic and can include tables, graphs, equations, algorithms, words, and computer simulations. Mathematics is a key tool for describing, predicting, and analyzing the world.

Summary

Students experience and navigate the world as an integrated whole. Language, literacy, mathematics, science, technology, and engineering are seamlessly interwoven in our everyday lives. The purposeful attention to relationships across content areas strengthens STE learning for all students. The Venn diagram below shows some ways in which these relationships overlap in state standards:



Relationships of disciplinary practices across the Massachusetts Curriculum Frameworks for English Language Arts and Literacy, Mathematics, and Science and Technology/Engineering (based on work by Tina Cheuk; ell.stanford.edu).

The disciplinary practices overlap and connect in multiple ways; with effective instruction, they can make learning relevant and meaningful for all students. Attention to the discipline-specific ways in which language is used within and across each of these areas is essential, as language is the medium through which learning occurs and knowledge is exchanged in all classrooms.

[This appendix draws from NGSS, Appendix D.]

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Appendix III
Disciplinary Core Idea Progression Matrix

Each disciplinary core idea spans pre-K to high school, with each grade span representing a reconceptualization or more sophisticated understanding of how students think about the core idea. In subsequent grades the students' thinking about a disciplinary core idea becomes more sophisticated and closer to a scientific and technical perspective.

The *Framework for K-12 Science Education* (NRC, 2012) provides specific criteria for what constitutes a core idea. To be regarded as core, each idea must meet at least two, though preferably three or four, of the following criteria:

> 1. Have broad importance across multiple sciences or engineering disciplines or be a key organizing principle of a single discipline.
> 2. Provide a key tool for understanding or investigating more complex ideas and solving problems.
> 3. Relate to the interests and life experiences of students or be connected to societal or personal concerns that require scientific or technological knowledge.
> 4. Be teachable and learnable over multiple grades at increasing levels of depth and sophistication. That is, the idea can be made accessible to younger students but is broad enough to sustain continued investigation over years.
>
> NRC, 2012, p. 31

The landscape charts on the following pages present the "progression matrix" and *briefly* describe the content at each grade span for each disciplinary core idea for pre-K–12. The full progressions can be seen in the NRC *Framework*. Strand maps are another way to visualize the progressions (see Appendix IV). This section does not endorse separating the disciplinary core ideas from science and engineering practices in curriculum, instruction, or assessment.

Planning an STE curriculum at any grade level is most effective when it is known what students have already been taught and what they should be learning in subsequent years. This matrix can be helpful in planning and aligning curricula to recognize how standards relate across grade spans, build upon each other, and may be integrated in curriculum. Core ideas do not, however, always define the best units of instruction. Schools and districts will likely group standards in combinations other than those shown in the matrix or in the standards themselves. Organizing the standards by disciplinary core idea provides an opportunity to see how students are supported in learning any one core idea from year to year.

Note that the core ideas for high school physical science are distributed across both introductory physics and chemistry. These are presented next to each other, but they do not represent a sequential progression from introductory physics to chemistry. The dotted line between them is meant to indicate this.

[This appendix draws from and is an adaptation of the NGSS, Appendix E.]

References

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Earth Space Science Progression

INCREASINGLY SOPHISTICATED SCIENCE

	Pre-K–2	3–5	6–8	9–10
ESS1.A The universe and its stars	Patterns of movement of the Sun, Moon, and stars as seen from Earth can be observed, described, and predicted.	Stars range greatly in their distance from Earth and this can explain their relative brightness.	N/A	Solar activity creates the elements through nuclear fusion. Astronomical evidence for the Big Bang theory comes from multiple sources.
		N/A	The solar system is part of the Milky Way, which is one of many billions of galaxies.	
ESS1.B Earth and the solar system		The Earth's orbit and rotation, and the orbit of the Moon around the Earth, cause observable patterns.	The solar system contains many varied objects held together by gravity. Solar system models explain and predict eclipses, lunar phases, and seasons.	Kepler's laws describe common features of the motions of orbiting objects. Changes in Earth's tilt and orbit result in cycles of climate changes such as ice ages.
ESS1.C The history of planet Earth	N/A	Patterns in rock formations and fossils indicate changes in landscapes over time.	Rock strata and the fossil record can be used as evidence to organize the relative occurrence of major historical events in Earth's history.	Past plate motions and plate tectonics explain why continental rocks are so much older than rocks of the ocean floor.
ESS2.A Earth materials and systems	Wind and water change the shape of the land.	The water cycle involves interactions of the four major Earth systems. Water, ice, wind, and organisms break rocks, soils, and sediments into smaller pieces and move them around.	Energy flows and matter cycles within and among Earth's systems, including the Sun and Earth's interior as primary energy sources. Plate tectonics is one result of these processes.	Feedback effects exist within and among Earth's systems.
ESS2.B Plate tectonics and large-scale system interactions	Maps show where things are located. One can map the shapes and kinds of land and water in any area.	Earth's physical features occur in patterns, as do earthquakes and volcanoes. Maps can be used to locate features and determine patterns in those events.	Plate tectonics is the unifying theory that explains movements of rocks at Earth's surface and geological features. Maps are used to display evidence of plate movement.	Radioactive decay and residual heat of formation within Earth's interior contribute to thermal convection in the mantle.

	Pre-K–2	3–5	6–8	9–10
ESS2.C The roles of water in Earth's surface processes	Water is found in many types of places and in different forms on Earth.	Most of Earth's water is in the ocean and much of the Earth's fresh water is in glaciers or underground.	Water cycles among land, ocean, and atmosphere, and is propelled by sunlight and gravity.	The planet's dynamics are greatly influenced by water's unique chemical and physical properties.
ESS2.D Weather and climate	Weather is the combination of sunlight, wind, snow or rain, and temperature in a particular region and time. People record weather patterns over time.	Climate describes patterns of typical weather conditions over different scales and variations. Historical weather patterns can be analyzed.	Complex interactions determine local weather patterns and influence climate, including the role of the ocean. Human activities affect global warming.	The role of radiation from the Sun and its interactions with the atmosphere, ocean, and land are the foundation for the global climate system.
ESS3.A Natural resources	Living things need water, air, and resources from the land, and they live in places that have the things they need. Humans use natural resources for everything they do.	Energy and fuels humans use are derived from natural sources and their use affects the environment. Some resources are renewable over time; others are not.	Resources are distributed unevenly around the planet as a result of past geologic processes.	Resource availability has guided the development of human society and use of natural resources has associated costs, risks, and benefits, including to global climate.
ESS3.B Natural hazards	In a region, some kinds of severe weather are more likely than others. Forecasts allow communities to prepare for severe weather.	A variety of hazards result from natural processes; humans cannot eliminate hazards but can reduce their impacts.	Mapping the history of natural hazards in a region helps explain related geological forces.	N/A
ESS3.C Human impacts on Earth systems	Things people do can affect the environment but they can make choices to reduce their impacts.	Societal activities can help protect Earth's resources and environments.	Human activities have altered the biosphere, sometimes damaging it, although changes to environments can have different impacts for different living things. Activities and technologies can be engineered to reduce people's impacts on Earth.	Sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources.

Life Science Progression

INCREASINGLY SOPHISTICATED SCIENCE

	Pre-K–2	3–5	6–8	9–10
LS1.A Structure and function	Plants and animals have external parts that they use to perform daily functions.	Organisms have both internal and external macroscopic structures that enable growth, survival, behavior, and reproduction.	All living things are made up of cells. An organism can be made of one cell (unicellular) or many cells (multicellular). Within cells, specialized structures are responsible for specific functions. In multicellular organisms, cells work together to form tissues and organs that are specialized for particular body functions.	Systems of specialized cells within organisms carry out essential functions of life. Any one system in an organism is made up of numerous parts. Feedback mechanisms maintain an organism’s internal conditions within certain limits and mediate behaviors.
LS1.B Growth and development of organisms	Parents and offspring engage in behaviors that help offspring survive. Plants and animals have a life cycle.	Reproduction is essential to every kind of organism. Organisms have unique and diverse life cycles, including birth/sprouting, growth, and death.	An organism’s structures and behaviors affect the probability of successful reproduction. An organism’s growth is affected by both genetic and environmental factors.	In multicellular organisms, the processes of mitosis and differentiation drive an organism’s growth and development. Each chromosome pair contains two variants of each gene. Offspring that result from sexual reproduction inherit one set of chromosomes from each parent.
LS1.C Organization for matter and energy flow in organisms	Animals obtain food they need from plants or other animals. Plants need air, water, and light. Plants do not eat food; instead, they make their own “food.”	Food provides animals with the materials and energy they need for body repair, growth, warmth, and motion. Plants acquire material for growth chiefly from air and water, and obtain energy from sunlight, which is used to maintain conditions necessary for survival.	Matter cycles between living and non-living parts of an ecosystem. Plants use the energy from light to make sugars through photosynthesis. Within individual organisms, food is broken down through cellular respiration, which rearranges molecules and releases energy.	Organisms are constantly breaking down and reorganizing matter. The hydrocarbon backbones of sugars produced through photosynthesis are used by organisms to make amino acids and other macromolecules that can be assembled into proteins or DNA. During cellular respiration, the bonds of macromolecules and oxygen are broken down to build new products and transfer energy.

	Pre-K–2	3–5	6–8	9–10
LS2.A Interdependent relationships in ecosystems	Plants and animals depend on their surroundings to get what they need.	Some animals eat plants for food and other animals eat the animals that eat plants, while decomposers restore some materials back to the soil. These relationships among organisms in an ecosystem are represented by food webs.	Organisms and populations are dependent on their environmental interactions both with other living things and with nonliving factors, any of which can limit their growth. Organisms compete for resources within ecosystems; typical interaction patterns include competitive, predatory, parasitic, and symbiotic relationships.	Ecosystems have carrying capacities resulting from biotic and abiotic factors. The fundamental tension between resource availability and organism populations affects genetic diversity within populations and biodiversity within ecosystems.
LS2.B Cycles of matter and energy transfer in ecosystems	[Content found in LS1.C, LS2.A, and ESS3.A]	Matter cycles between the air, water, and soil and among organisms as they live and die.	The matter that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem. Food webs model the transfer of energy as well as matter among producers, consumers, and decomposers within an ecosystem. The Sun provides the energy for most ecosystems on Earth.	Photosynthesis captures energy in sunlight and stores it in chemical bonds of matter. Most organisms rely on cellular respiration to release energy in these bonds to power life processes. About 90% of available energy is lost from one trophic level to the next, resulting in fewer organisms at higher levels. At each link in an ecosystem, elements are combined in different ways and matter and energy are conserved. Photosynthesis, cellular respiration and decomposition are key components of the global carbon cycle.

<table>
<tr><th></th><th>Pre-K–2</th><th>3–5</th><th>6–8</th><th>9–10</th></tr>
<tr><td>LS2.C Ecosystem dynamics, functioning, and resilience</td><td>N/A</td><td>When the environment changes some organisms survive and reproduce, some move to new locations, some new organisms move into the transformed environment, and some die.</td><td>Ecosystems are dynamic; their characteristics vary over time. Changes to any component of an ecosystem can lead to shifts in all of its populations. The completeness or integrity of an ecosystem’s biodiversity is often used as a measure of its health.</td><td>If a biological or physical disturbance to an ecosystem occurs, including one induced by human activity, the ecosystem may return to its more or less original state or become a very different ecosystem, depending on the complex interactions within the ecosystem. The ability of an ecosystem to both resist and recover from change is a measure of its overall health.</td></tr>
<tr><td>LS3.A Inheritance of traits</td><td rowspan="2">Young organisms are very much, but not exactly, like their parents and also resemble other organisms of the same kind.</td><td rowspan="2">Different organisms vary in how they look and function because they have different inherited information; the environment also affects the traits that an organism develops. Variations of a trait exist in a group of similar organisms.</td><td>Organisms reproduce, either sexually or asexually, and parents transfer their genetic information to offspring. An individual’s traits are largely the result of proteins, which are coded for by genes. Genes are located in the chromosomes of cells.</td><td>Nearly every cell in an organism contains an identical set of genetic information on DNA but the genes expressed by cells can differ. In sexual reproduction, genetic material in chromosomes of DNA is passed from parents to offspring during meiosis and fertilization.</td></tr>
<tr><td>LS3.B Variation of traits</td><td>In sexual reproduction, each parent randomly contributes half of its offspring’s genetic information, resulting in variation between parent and offspring. Genetic information can be altered because of mutations, which may result in beneficial, negative, or no change to traits of an organism.</td><td>The variation and distribution of traits in a population depend on genetic and environmental factors. Sources of genetic variation include gene shuffling and crossing over during meiosis, recombination of alleles during sexual reproduction, and mutations. Mutations can be caused by environmental factors or errors in DNA replication, or from errors that occur during meiosis. Only mutations that occur in gametes can be passed on to offspring.</td></tr>
</table>

	Pre-K–2	3–5	6–8	9–10
LS4.A Evidence of common ancestry and diversity	N/A	Fossils provide evidence about the types of organisms and environments that existed long ago. Some living organisms resemble organisms that once lived on Earth.	The fossil record documents the existence, diversity, extinction, and change of many life forms and their environments through Earth's history. Comparisons of anatomical similarities among both living and extinct organisms enables the inference of lines of evolutionary descent.	The fossil record and genetic, anatomical, and developmental homologies provide evidence for common descent among organisms.
LS4.B Natural selection	N/A	Differences in characteristics between individuals of the same species can provide advantages in surviving and reproducing.	Both natural and artificial selection result from certain traits giving some individuals an advantage in surviving, reproducing, and passing on genes to their offspring, leading to predominance of these advantageous traits in a population.	Natural selection, including the special cases of sexual selection and coevolution, works together with genetic drift and gene flow (migration) to shape the diversity of organisms on Earth through speciation and extinction.
LS4.C Adaptation	Different places on Earth each have their own unique assortment of organisms.	Particular organisms can only survive in particular environments. In any environment, some kinds of organisms, and some individuals of a given species, survive better than others.	An adaptation is a trait that increases an individual's chances of surviving and reproducing in their environment. Species can change over time in response to changes in environmental conditions through adaptation by natural selection acting over generations.	Evolution by natural selection occurs when there is competition for resources and variation in traits that lead to differential ability of individuals to survive, reproduce, and pass on genes. As the environment changes, so, too, do the traits that confer the strongest advantages.

Physical Science Progression

INCREASINGLY SOPHISTICATED SCIENCE

	Pre-K–2	3–5	6–8	9–10 (Introductory Physics)	10–11 (Chemistry)
PS1.A Structure of matter (includes PS1.C, nuclear processes)	Matter exists as different substances that have observable different properties. Different properties are suited to different purposes. Matter can be divided into smaller pieces, even if it can't be seen. Objects can be built up from smaller parts.	Because matter exists as particles that are too small to see, matter is always conserved even if it seems to disappear. Measurements of a variety of observable properties can be used to identify particular materials.	That matter is composed of atoms and molecules can be used to explain the properties of substances, diversity of materials, how mixtures will interact, states of matter, phase changes, and conservation of matter. States of matter can be modeled in terms of spatial arrangement, movement, and strength of interactions between particles. Characteristic physical properties unique to each substance can be used to identify the substance.	N/A	The sub-atomic structural model and interactions between electric charges at the atomic scale can be used to explain the structure and interactions of matter. Repeating patterns of the periodic table reflect patterns of sub-atomic structure and can be used to predict properties of elements and classes of chemical reactions. Atoms are conserved in a reaction; thus the mass does not change.
PS1.B Chemical reactions	Heating and cooling substances cause changes that are sometimes reversible and sometimes not.	Chemical reactions that occur when some substances are mixed can be identified by the emergence of substances with different properties; the total mass remains the same.	Some mixtures of substances can be separated into component substances. Reacting substances rearrange to form different molecules with different properties, but the number of atoms is conserved. Some reactions release energy and others absorb energy depending on the type and concentration of reactants.	N/A	Chemical processes and reaction rates are understood in terms of collisions of molecules, rearrangement of atoms, and changes in energy as determined by properties of elements involved. Knowledge of conservation of atoms with chemical properties and electrical charges can be used to describe and predict chemical reactions. Main types of reactions include transfer of electrons (redox) or hydronium ions (acids/bases). Changes in pressure, concentration, or

	Pre-K–2	3–5	6–8	9–10 (Introductory Physics)	10–11 (Chemistry)
					temperature affect the balance between forward and backward reaction rates (equilibrium). Ionic and covalent bonds can be predicted based on the types of attractive forces between particles.
PS2.A Forces and motion	Pushes and pulls can have different strengths and directions, and can change the speed or direction of an object's motion or start or stop it. Bigger pushes and pulls cause bigger changes in an object's motion.	The effect of unbalanced forces on an object results in a change of motion. Some forces act through contact; some forces act even when the objects are not in contact. The gravitational force of Earth acting on an object near Earth's surface pulls that object toward the planet's center.	The role of the mass of an object must be qualitatively accounted for in any change of motion due to the application of a force.	Newton's second law *(F = ma)* and the conservation of momentum can be used to predict changes in the motion of macroscopic objects.	N/A
PS2.B Types of interactions			Forces that act at a distance involve fields that can be mapped by their relative strength and effect on an object. Solutes can change the properties of solvents by creating charged particles.	Forces at a distance are explained by fields that can transfer energy and can be described in terms of the arrangement and properties of interacting objects and the distance between them. These forces can be used to describe the relationship between electrical and magnetic fields.	Electrical forces between electrons and the nucleus of atoms explain chemical patterns. Intermolecular forces determine atomic composition, molecular geometry and polarity, and, therefore, structure and properties of substances. The kinetic-molecular theory describes the behavior of gas in a system.

	Pre-K–2	3–5	6–8	9–10 (Introductory Physics)	10–11 (Chemistry)
PS3.A and 3.B Definition and conservation of energy and energy transfer	[Content found in PS3.D]	Moving objects contain energy. The faster the object moves, the more energy it has. Energy can be moved from place to place by moving objects, or through sound, light, or electrical currents. Energy can be converted from one form to another form.	Kinetic energy can be distinguished from the various forms of potential energy. Energy changes to and from each type can be tracked through physical or chemical interactions. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter.	The total energy within a physical system is conserved. Energy transfer within and between systems can be described and predicted in terms of energy associated with the motion or configuration of particles (objects).	In a closed chemical system, the transfer of energy involves enthalpy change and entropy change, though the total energy is conserved. Chemical reactions move toward overall stability, toward a more uniform energy distribution and more stable molecular and network structures.
PS3.C Relationship between energy and forces	[Content found in PS2.B]	When objects collide, contact forces transfer energy so as to change the objects' motions.	When two objects interact in contact or at a distance, each one exerts a force on the other, and these forces can transfer energy between them.	Fields contain energy that depends on the arrangement of the objects in the field.	N/A
PS3.D Energy in chemical processes and everyday life	Sunlight warms Earth's surface. Friction warms objects that rub against each other.	Energy can be "produced" or "used" by converting stored energy. Plants capture energy from sunlight, which can later be used as fuel or food.	Sunlight is captured by plants and used in a reaction to produce sugar molecules, which can be reversed by burning those molecules to release energy.	Photosynthesis is the primary biological means of capturing radiation from the Sun.	N/A

	Pre-K–2	3–5	6–8	9–10 (Introductory Physics)	10–11 (Chemistry)
PS4.A Wave properties	Sound can make matter vibrate and vibrating matter can make sound.	Waves are regular patterns of motion, which can be made in water by disturbing the surface. Waves of the same type can differ in amplitude and wavelength. Waves can make objects move.	A simple wave model has a repeating pattern with a specific wavelength, frequency, and amplitude, and mechanical waves need a medium through which they are transmitted. This model can explain many phenomena, including sound and light.	The wavelength and frequency of a wave are related to one another by the speed of the wave, which depends on the type of wave and the medium through which it is passing.	N/A
PS4.B Electromagnetic radiation	Some materials allow light to pass through, block light (creating shadows), or redirect light.	Objects can be seen when light reflected from their surface enters our eyes.	The construct of a wave is used to model how light interacts with objects.	Both an electromagnetic wave model and a photon model explain features of electromagnetic radiation broadly and describe common applications of electromagnetic radiation, including communications and energy generation.	N/A
PS4.C Information technologies and instrumentation	People use devices to send and receive information.	Patterns can allow information to be encoded, sent, received, and decoded.	Waves can be used to transmit digital information. Digitized information is composed of a pattern of "1s" (ones) and "0s" (zeros).	N/A	N/A

Technology/Engineering Progression
INCREASINGLY SOPHISTICATED SCIENCE

	Pre-K–2	3–5	6–8	9–10
ETS1.A Define design problems	Situations that people want to change can be solved through engineering.	A possible solution to a simple problem must meet specified criteria and constraints.	The precision of criteria and constraints is important to an effective solution, as are considerations that are likely to limit possible solutions.	A broad range of considerations, criteria, and constraints must be considered for problems of social and global significance.
ETS1.B Develop solutions	Solutions can be conveyed through visual or physical representations.	Solutions need to be researched and compared.	Parts of different solutions can be combined to create new solutions.	Major problems need to be broken into smaller problems that can be solved separately.
ETS1.C Optimize solutions	Solutions are compared, tested, and evaluated.	Solutions are improved based on results of simple tests, including failure points.	Systematic processes are used to iteratively test and refine a solution.	Criteria, trade-offs, and social and environmental impacts are considered as a complex solution is tested and refined.
ETS2.A Materials and tools	[Content found in PS1.A]	[Content found in PS1.A]	Materials used in technologies are chosen based on the material properties needed for a particular purpose. Physical processing can change the particulate structure of materials and their properties.	Characteristics of material properties can be tested, defined, and graphed. New materials can be synthesized through chemical and physical processes.
ETS2.B Manufacturing	N/A	N/A	The design and structure of any particular technology product reflects its function. Products can be manufactured using common processes controlled by either people or computers.	Manufacturing processes can transform material properties to meet a need. Particular manufacturing processes are chosen based on the product design, materials used, precision needed, and safety. Computers can help with all of these.
ETS3.A Analyzing technological systems	N/A	N/A	Generally, technology systems are built to accomplish specific goals, rely on defined inputs, carry out specific processes, generate desired outputs, and include feedback for control. Major systems are often designed to work together.	Technological systems are often composed of multiple subsystems, in which the output of one subsystem is the input of another.

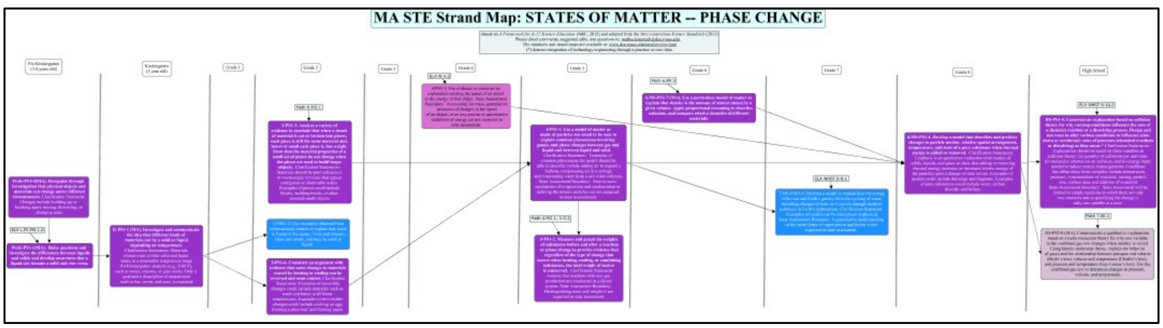
	Pre-K–2	3–5	6–8	9–10
ETS3.B Technological systems society relies on (examples)	N/A	Technology is the modification of the natural or designed world to meet people's needs, often made of parts that work together.	Three critical systems society relies on are communications, transportation, and structural systems. Components of a communication system allow messages to be sent long distances. Transportation systems move people and goods using vehicles and devices. And structural systems allow for physical structures that meet human needs.	Communications systems can be analog or digital and use various media. Vehicles can be modified for specific purposes and performance characteristics. Structural analysis must account for active and static loads, as well as properties of materials used in their construction.
ETS4.A Using, transferring, converting energy and power in technological systems	NA	[Content found in PS3.A and 3.B]	Machines convert energy to do work. [Content found in PS3.A and 3.B]	Most technological systems use energy and resources to accomplish desired tasks. People continually work to increase the effectiveness and efficiency of these systems. Technological systems often rely on open or closed fluid systems, particularly hydraulic systems to accomplish tasks requiring large forces.
ETS4.B Thermal systems	N/A	N/A	[Content found in PS3.A and 3.B]	Thermal processes and material properties must be considered in the design of certain technologies, particularly buildings.
ETS4.C Electrical systems	N/A	N/A	[Content found in PS2.B]	The use of electrical circuits and electricity is critical to most technological systems in society. Electrical systems can be AC or DC, rely on a variety of key components, and are designed for specific voltage, current, and/or power.

Appendix IV
Strand Maps of Science and Technology/Engineering Standards

The standards reflect coherent progressions of learning that support the development of core ideas across grades. This makes it useful to visualize how concepts progress across grade spans and are related across disciplines when planning and aligning curricula (horizontally and vertically).

Strand maps are designed for this purpose. Learning is facilitated when new and existing knowledge is structured around core ideas rather than discrete bits of information. The strand maps show the conceptual relationship between concepts in standards within and across grades.

Sample STE strand map showing linked concepts from pre-K (left) to high school (right)

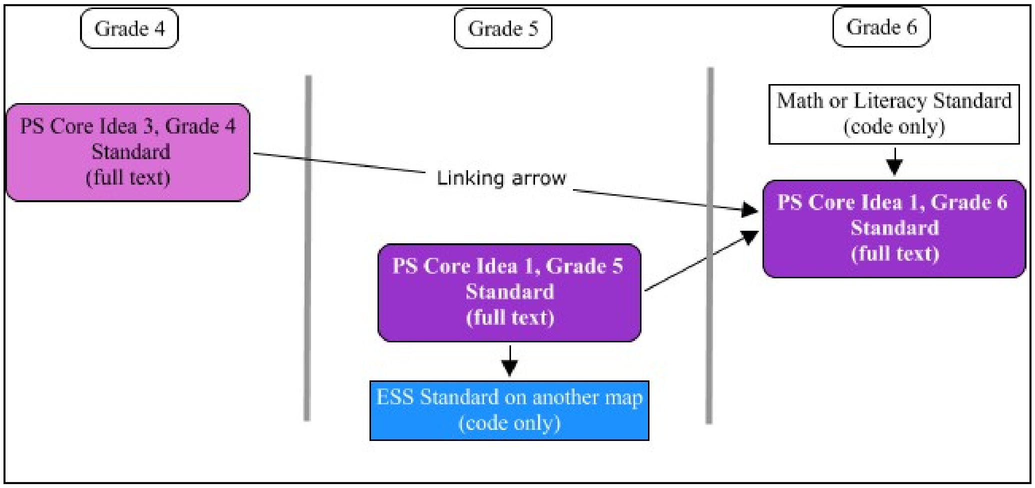


Individual teachers can use strand maps to identify concepts that should be the focus of pre-assessment, to convey to students how the standard they are learning will contribute to future learning, and to cluster standards into effective units of study. Schools and districts have found strand maps to be particularly useful in vertical team meetings, curriculum mapping workshops, and interdisciplinary meetings. Planning an STE curriculum at any grade level is most effective when it is known what students have already been taught and what they will learn in subsequent years.

Features of Strand Maps

The strand maps are presented by discipline (e.g., life science, physical science) and grade span (pre-K–5, middle and high school). Each discipline is identified by a thematic set of color-coded standards (e.g., Earth and space science is a blue scheme) and each core idea is a consistent color. Please note that pre-K–5 physical science includes technology/engineering and high school physical science includes both introductory physics and chemistry. Topical examples (e.g., weather and climate, states of matter and phase change) illustrate how concepts relevant to a particular topic relate across disciplines and progress across grades.

Each strand map includes the full standards in individual cells, organized by the grade level or course and color coded by discipline and core idea. Arrows link certain standards, highlighting how concepts within particular standards are related and progress. An arrow leaving a standard implies that the concept is fundamental to learning the concept of the next/connected standard—it would be difficult to learn the next standard without knowing the previous/connected standard(s). In addition to links among science standards, links from mathematics and English language arts standards are also included in clear cells. Again, their inclusion implies that fluency with those standards is an important contributor to learning the linked science standards. While the full STE standard is included in each cell of the strand maps, the mathematics and literacy standards are only indicated with their codes. The key below provides an overview of the structure of the strand maps.



Key showing the basic structure and components of an STE strand map.

The linking arrows do not represent connections or progressions of practices in the standards, only concepts. Nor is there any particular research that suggests particular arrows are fixed or true; the linking arrows reflect professional judgment by informed and experienced STE educators and researchers.

The strand maps only represent *conceptual* connections and progressions across grades. For those developing curricula or asking students to develop concept maps for particular topics or core ideas, there would be many more possible connections between standards. The main idea of the strand maps is to show how ideas and understanding develop over time, to visualize what contributes to a student learning any particular standard and how that enables progressions of learning over time.

Accessing STE Strand Maps

The maps can be accessed on the Department's website in several formats:

- A one-page (PDF) document useful for viewing electronically (zoom in several hundred percent).
- A multipage (PDF) document useful for printing (cut off selected edges, then tape together).
- The original CMapTools file useful for manipulating or changing the strand maps; any map can be printed at desired scale from within the application (download free CMapTools from cmap.ihmc.us/Download).

The strand maps may be updated periodically or additional topic maps may be added. Please provide input, share maps you have created, or comment on how you have used them by emailing mathsciencetech@doe.mass.edu.

Curriculum-Related Appendices

Appendix V
The Case for an Integrated Approach in Grades Pre-K–8

The goal of a quality STE education is to produce scientifically and technologically literate citizens who can solve complex, multidisciplinary problems through analytical and innovative thinking in real-world applications needed for college and career success. An integrated model for the Massachusetts pre-K to grade 8 STE standards reflects:

- That science is complex and multidisciplinary.
- Research on learning in science that shows expert knowledge develops through interdisciplinary connections, not isolated concepts or practices.
- Effective research-based practices for curriculum and instruction in science and engineering.

Science as Complex and Multidisciplinary

The nature of STE is complex and multidisciplinary. Scientists and engineers typically do not work in isolated disciplines of physics, biology, or engineering: they create networks of professionals within and across disciplines who can contribute knowledge, share ideas and methods, and critique explanations and evidence. This is also the case when citizens collaborate to apply scientific and technical knowledge to community or workplace applications. Important practices, such as engaging in argument from evidence, modeling, and communicating information, do not occur in isolation but are always in the context of disciplinary concepts and rely on feedback from within and across scientific, technical, and workplace communities. Students' understanding of science, technology, and engineering as interdisciplinary and interconnected is enhanced by basing the pre-K to grade 8 standards in an integrated model with multiple disciplines at each grade. The cross-disciplinary aspects reflected through the nature of science and crosscutting concepts reinforce the multidisciplinary nature of STE (also see Appendix VIII).

Research on Learning in Science

Learning theory research shows that expert knowledge is developed more effectively when learning is contextualized in interdisciplinary real-world connections than through isolated content or practice (e.g., NRC, 2012; Schwartz et al., 2009). An integrated STE curriculum that reflects what we know about the learning of science and how mastery develops over time promotes deeper learning in science (e.g., Wilson et al., 2010). Students develop understanding more effectively while learning content and practices together (e.g., NRC, 2005, 2009, 2012). Learning progressions recognize that learning requires revision of *networks* of understanding, not revision of individual concepts (or misconceptions) (e.g., Alonzo & Gotwals, 2012; Corcoran et al., 2009; NRC, 2012). If teachers understand where their students are in their understanding of core ideas, and anticipate what students' misconceptions and struggles may be (e.g., Banilower et al., 2010; Driver et al., 1985, 1994; Keeley et al., 2005; Stanford University, 2012), they can better differentiate instruction and provide scaffolding that allows students to develop an integrated, deeper understanding of the STE content.

Attention to progressions of learning requires us to consider what concepts or skills a student must learn first to effectively learn subsequent concepts. There are many such considerations *within* disciplines, where the standards are built on progressions of specific disciplinary core ideas, and others *across or between* disciplines. Attention to a progression of learning highlights how concepts are sequenced and relate; this is a cognitive perspective that is distinct from a curricular perspective in which many other connections or relationships can be made to define related sets of concepts for curriculum and instruction. The strand maps (see Appendix IV) highlight cognitive connections. These provide guidance for ensuring that prerequisite concepts are established before others are taught to support the learning of core ideas over time. This includes considerations of the mathematics and literacy standards necessary to learn a particular STE standard.

Students should engage with science and engineering practices and concepts that range across disciplines. Following this model through grade 8 allows students to build coherent understandings and skills based upon coherent progressions of learning. In this way, the integrated approach to the teaching and learning of science in pre-K to grade 8 respects learning as a purposeful progression.

Effective Science Curricula and Instruction

The Guiding Principles discuss the qualities of effective STE programs, highlighting the need for coherence, connections, and relevance. Effective science curricula and instruction help pre-K to grade 8 students to interrelate and apply science disciplines, link to their prior knowledge, and analyze the world around them. Purposeful design of curricula and instruction scaffolds students to understand the natural world in an increasingly scientifically accurate way and understand the nature of science.

A Curricular Decision

A course curriculum should reflect a rationale, assumption, or belief about how students best engage with the entire set of core ideas and practices. That rationale, assumption, or belief explains and guides the placement of certain topics together in a particular grade and the sequence of topics over years. These are often represented as grade-level themes, grade-span storylines, and/or sequential knowledge construction that puts each particular topic into a context and makes learning more relevant for students. Pre-K to grade 5 curricula and instruction are often designed in an integrated approach by theme; the same is true for grade 6–8 curricula. The standards for grades pre-K–8 have been articulated from this perspective, with a thematic rationale for each set of standards for each grade. Note that just putting standards from multiple disciplines in one grade does not necessarily result in integrated units of study: it allows for and even promotes that, but it is up to districts, schools, and curriculum developers to determine the nature of the integration through particular curriculum design. This approach provides a theme to each grade that informs curricula, but does not define or constrain local curricular design.

The particular distribution of pre-K–5 STE standards is consistent with the NGSS. Massachusetts has added an introductory paragraph to each grade to articulate its theme. Standards from each discipline are generally aligned to the grade-level theme.

The middle school standards also include an integration of disciplines in each grade, organized by a theme. Middle school curriculum design is more variable, although an integrated approach is the most common. There are two common structures for middle school course design: those that *integrate* the disciplines and those that are *discipline-specific,* focusing on one discipline each year. Massachusetts Student Course Schedule data from the 2012–2013 school year for middle school science showed that the vast majority of schools appear to take an integrated approach at each grade. About 195,000 students were in integrated middle school science courses versus about 23,500 students in discipline-specific middle school science courses (please note there are some inconsistencies with how schools use course codes, so there is some variability in the data). There is not, however, any noticeably consistent or prevalent model for how integrated courses are defined, constructed, or organized across districts. There is also no consistency in which discipline-specific course sequence is used. An analysis of standards from 10 internationally competitive countries indicates that 7 of those 10 design integrated sequences from elementary through middle and even early high school (Achieve, 2010). Given this evidence and the rationales presented above, the grade 6–8 standards are presented as integrated standards organized around a coherent theme.

Please note that state assessment (MCAS) will remain at grade 5 and grade 8 and assess the full three-year *grade-span* in each case. Given this, districts can continue to organize the grade-by-grade standards in any number of configurations to meet their locally designed curriculum. Presenting the standards by grade level is intended to provide more continuity and consistency across schools and districts, enhance support for resource development and sharing, and better address challenges such as student transience.

Conclusion

A pre-K to grade 8 integrated model allows students to be equally prepared to enter introductory physics, Earth and space science, biology, or technology/engineering in grade 9 without a gap of a year or longer of being engaged in some of the core ideas of each domain. The specific and deliberate sequencing of the standards can lead purposefully to the high school standards for each STE discipline.

Presenting standards by grade provides clear and consistent guidance for pre-K to grade 8 and allows districts and schools to align curricula, instruction, assessment, and professional development to particular grades. Districts and schools will be able to share STE curriculum resources, teacher professional development, district determined measures, and other resources. If a student transfers between schools or districts in the state, there would be a common pathway and, hopefully, a less abrupt change or gap in his/her science learning. An integrated approach for pre-K–8 reflects the multidisciplinary nature of STE and research on science learning, curricula, and instruction.

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Appendix VI
Importance of Science and Engineering in Early Education

Science and engineering are key components of early education (birth to age eight), and a natural focus for young children who are beginning to develop their own understandings of the world and how it works. By introducing children to science and engineering at a young age, we support their curiosity, promote their understanding, and give them the tools they need to investigate, design, observe, and draw evidence-based conclusions about the world. Children who are able to think critically, solve problems, and base their ideas on evidence at an early age will have a strong foundation as they engage with a world that is increasingly rooted in science, technology, and engineering.

Young children are predisposed to doing and learning science and engineering. For them, it is a form of high-level exploratory and constructive play that supports their critical thinking skills, problem-solving abilities, and their social and emotional development. Much like scientists and engineers, children want to make sense of the world and solve problems they see around them. Young children ask “how” and “why” and “what if” questions about everything around them and are naturally inclined to explore potential answers to their questions using all their senses. To build on their natural curiosity, young children should be exposed to different scientific contexts and concepts to help them refine and construct their thinking. This can be reinforced when science and engineering are accessible and engaging, modeling interest, wonder, and enthusiasm.

Educators of young children can effectively support good science and engineering by engaging them in science and engineering practices. Allowing children to pose questions and problems, and helping them expand on ways to begin to answer those questions and solve those problems, gives students the opportunity to be active participants in their own learning. Educators can give children varied opportunities to engage in science and engineering practices and concepts, such as through hands-on investigations, design projects, centers, literacy, and extended studies of natural phenomena. Such approaches foster development of scientific and technical reasoning because it is connected to their own experiences.

Science and engineering can also provide a compelling context for young children to learn literacy and mathematics. Science and engineering experiences offer contexts to form the foundations of reading, writing, speaking and listening, and language development. Young children encounter new vocabulary, begin to use language in a variety of ways, create visuals to clarify ideas, and participate in collaborative conversations with diverse partners to generate explanations and solutions. Science and engineering also require the use of applied mathematics. Young children begin counting and quantifying numbers and exploring shapes and the relationships among them. Integrating science and engineering with literacy and mathematics engages children with the idea that the disciplines work in conjunction with each other and builds a strong foundation as they advance to later grades with more complex concepts and practices.

Aside from furthering academic development, science and engineering build young children’s identity as scientists and engineers. Their curiosity and need to make sense of their environment make science and engineering exciting and engaging parts of the early childhood experience. Engaging curricula and instruction develop positive attitudes toward science and engineering and allows children to develop knowledge and skills that will guide and enrich their lives. Allowing children to explore the natural and human-made world though relevant experiences, in and out of the classroom, supports their use of science and engineering to understand and interact with the world.

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Appendix VII
Science and Technology/Engineering Laboratories

The integration of science and engineering practices with disciplinary core ideas has direct implications for the design of active learning experiences for students. This means students in STE learning environments at all grade levels should regularly be mentally and physically engaged (Clough, 2002). Current Massachusetts policy provides for districts to make local determinations of what constitutes an inquiry- or design-based STE curriculum, and what constitutes the definition of a “laboratory science” course (in high school). What should matter in defining quality STE learning experiences is what students are doing, not where they are doing it.

STE experiences, at every level, need to account for appropriate physical space (e.g., MSBA, 2010), reasonable equipment and materials, and safety (see Appendix XI).

Elementary Labs

There are many possibilities for pre-K–5 STE learning experiences, in the classroom or in and around the school. Elementary grades should introduce students to practices and procedures that generally start with teachers facilitating and leading students to observe and investigate natural phenomena, interact with real objects and/or models, and collect and manipulate different types of data. As students gain new knowledge, ask questions, and analyze and discuss evidence related to their work, they can design and develop their own STE experiences. They learn to work together or individually to carry out their own investigations, generate and design solutions, and use evidence to communicate and demonstrate understanding.

The physical space allocated for pre-K–5 STE experiences can vary widely. Spaces that are more open and have mobile tables can be configured to accommodate a variety of materials, equipment, and experiences. However, STE experiences take place in a wide variety of settings, including dedicated science classrooms, regular classrooms, athletic fields, school or community gardens, or nearby parks.

STE equipment can include hand lenses, a variety of measuring tools, microscopes, hand tools, interactive equipment, or computers that provide access to scientific databases, models, simulations, and visualizations that are age appropriate for pre-K–5 students. (See Appendix XI for information on safety in STE classrooms.)

Middle and High School Labs

Middle and high school lab experiences should offer a wide range of learning opportunities for STE concepts and practices. Striking a balance between teacher-led lab experiences and student-driven investigations is optimal for middle and high school students. Opportunities for students to interact directly with natural phenomena, design problems to understand empirical data that they or others may have collected, and grapple with scientific error, as they analyze, interpret, and debate their lab findings, are essential for understanding science content and practices. Middle and high school students can design and develop authentic lab experiences based on questions that emerge from instruction and increase their ability to collaborate effectively.

The physical space allocated for STE labs varies depending on the types of experiences planned, equipment needed, and the availability of resources. Generally, middle and high school lab spaces are larger than a typical classroom to account for safety and equipment and have the flexibility to be rearranged for difference types of experiences.

Lab equipment may include access to a water source and sinks, visible and accessible equipment, measuring devices, safety equipment, refrigerators, dishwashers, heating equipment, and standing-height and/or moveable tables. Other equipment found in labs can include hand tools, interactive models and devices, and computers. (See Appendix XI for information on safety in STE classrooms.)

Defining "Laboratory Science" Courses in High School

The inclusion of science and engineering practices in the standards suggests that the key factor in defining a "laboratory science" course is the nature and prevalence of the active learning experience. A definition of such courses should include two critical elements:

1. A balance between open and procedural investigations in which students learn and apply science and engineering practices.
2. The percent of course time engaged in inquiry- or design-based experiences.

Any course aligned to the STE standards, including technology/engineering courses, can be designated as a laboratory course. STE curricula should give students regular opportunities to develop distinct science and engineering practices and occasional opportunities to apply those together as a collective set of practices. A defined number of minutes, or an extra course period, can be used for—but is not the critical feature of—a lab definition. "Laboratory science" does not have to be in a laboratory; effective STE learning also occurs through field work, in a sufficiently supplied traditional classroom, through project-based experiences, in well-designed virtual courses, and in other learning environments (e.g., out of school time, see Appendix X). *America's Lab Report* (NRC, 2006), which reviewed research and best practices across the country, supports these perspectives.

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Appendix VIII
Value of Crosscutting Concepts and Nature of Science in Curricula

Crosscutting Concepts in Curricula

Crosscutting concepts are overarching themes that emerge across all science and engineering disciplines. These themes provide the context for disciplinary core ideas and enable students to "develop a cumulative, coherent, and usable understanding of science and engineering" (NRC, 2012, p. 4-1). Thus, crosscutting concepts bridge engineering, physical, life, and Earth/space sciences, and offer increased opportunities for organizing science and technology/engineering curricula across disciplines. The *Framework for K–12 Science Education* (NRC, 2012) defines crosscutting concepts as "concepts that bridge disciplinary boundaries, having explanatory value throughout much of science and engineering" (p. 83).

The NRC *Framework* identifies nine crosscutting concepts that bridge disciplines, uniting core ideas across STE. These concepts are intended to help students deepen their understanding of the disciplinary core ideas, and develop a coherent and scientifically based view of the world. They are:

1. **Patterns.** Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.
2. **Cause and Effect: Mechanism and Explanation.** Events have causes, sometimes simple, sometimes multifaceted. A major activity of science and engineering is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts or design solutions.
3. **Scale, Proportion, and Quantity.** In considering phenomena or design solutions, 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.
4. **Systems and System Models.** Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.
5. **Energy and Matter: Flows, Cycles, and Conservation.** Tracking fluxes of energy and matter into, out of, and within systems, helps one understand the systems' possibilities and limitations.
6. **Structure and Function.** The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.
7. **Stability and Change.** For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.
8. **Interdependence of Science, Engineering, and Technology.** Scientific inquiry, engineering design, and technological development are interdependent.
9. **Influence of Engineering, Technology, and Science on Society and the Natural World.** Scientific and technological advances can have a profound effect on society and the environment.

The NRC *Framework* notes that crosscutting concepts have been featured prominently in other science documents about what all students should learn for the past two decades. They have been called "common themes" in *Science for All Americans* (AAAS, 1989) and *Benchmarks for Science Literacy* (AAAS, 1993), and "unifying concepts and processes" in *National Science Education Standards* (NRC, 1996). Although these ideas have been consistently included in previous standards documents, the NRC *Framework* recognizes that "students have often been expected to build such knowledge without any explicit instructional support" (NRC, 2012, p. 83). Crosscutting concepts can help students think of science learning not as memorization of isolated or disconnected facts, but as integrated and interrelated concepts. This is a fundamental understanding of STE that requires explicit instruction to help all students make connections among big ideas that cut across disciplines.

Principles for Integrating Crosscutting Concepts in Curricula

The NRC *Framework* recommends embedding crosscutting concepts in the STE curriculum beginning in the earliest years of schooling and suggests a number of principles for how they can be used:

- **Use crosscutting concepts in curricula and instruction to help students better understand core ideas in STE.** When students encounter new phenomena or design problems—whether in a science lab, field trip, or on their own—they need mental tools to help engage in and come to understand the phenomena from a scientific and technological point of view. Familiarity with crosscutting concepts can provide that perspective. For example, when approaching a complex phenomenon (either a natural phenomenon or a mechanical system), it makes sense to begin by observing and characterizing the phenomenon in terms of patterns. A next step might be to simplify the phenomenon by thinking of it as a system and modeling its components and how they interact. In some cases it would be useful to study how energy and matter flow through the system, or to study how structure affects function (or malfunction). These preliminary studies may suggest explanations for the phenomena; these could be checked by predicting patterns that might emerge if the explanation is correct, then matching those patterns with those observed in the real world.
- **Use crosscutting concepts in curricula and instruction to help students better understand science and engineering practices.** Because these concepts address fundamental aspects of the world, they also inform the way humans attempt to understand it. Different crosscutting concepts align with different practices; when students carry out these practices, they are often addressing one of these crosscutting concepts. For example, when students analyze and interpret mathematical or visual data, they are often looking for patterns in observations. The practice of planning and carrying out an investigation is often aimed at identifying cause and effect relationships: If you poke or prod something, what will happen? The crosscutting concept of "Systems and System Models" is clearly related to the practice of developing and using models.
- **Repeat crosscutting concepts in different contexts to build familiarity.** While repetition is not a feature of the standards themselves, repeating crosscutting concepts within and across pre-K−12 helps them "become common and familiar touchstones across the disciplines and grade levels" (NRC, 2012, p. 83).
- **Crosscutting concepts should grow in complexity and sophistication across the grades.** As students grow in their understanding of the science disciplines, curricula should reflect an increasing depth of crosscutting concepts as well. The charts below (from the NGSS) describe increasingly sophisticated understandings of the crosscutting concepts across grade spans that can or should be integrated into curricula and instruction.

Progression of Crosscutting Concepts Across the Grades

Following is a brief summary of how each crosscutting concept increases in complexity and sophistication across the grades. See the NRC *Framework* for a detailed description of the substance and particulars of each.

1. Patterns

Progression Across the Grades
In grades pre-K–2, students can recognize that patterns in the natural and human-designed world can be observed, used to describe phenomena, and used as evidence.
In grades 3–5, students can identify similarities and differences in order to sort and classify natural objects and designed products. They identify patterns related to time, including simple rates of change and cycles, and use these patterns to make predictions.
In grades 6–8, students can recognize that macroscopic patterns are related to the nature of microscopic and atomic-level structure. They identify patterns in rates of change and other numerical relationships that provide information about natural and human designed systems. They use patterns to identify cause and effect relationships and use graphs and charts to identify patterns in data.
In grades 9–12, students can observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. They recognize that classifications or explanations used at one scale may not be useful or need revision using a different scale, thus requiring improved investigations and experiments. They use mathematical representations to identify certain patterns and analyze patterns of performance in order to re-engineer and improve a designed system.

2. Cause and Effect: Mechanism and Explanation

Progression Across the Grades
In grades pre-K–2, students can learn that events have causes that generate observable patterns. They design simple tests to gather evidence to support or refute their own ideas about causes.
In grades 3–5, students can routinely identify and test causal relationships and use these relationships to explain change. They understand events that occur together with regularity might or might not signify a cause and effect relationship.
In grades 6–8, students can classify relationships as causal or correlational and recognize that correlation does not necessarily imply causation. They use cause and effect relationships to predict phenomena in natural or designed systems. They also understand that phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability.
In grades 9–12, students can understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They also propose causal relationships by examining what is known about smaller-scale mechanisms within the system. They recognize that changes in systems may have various causes that may not have equal effects.

3. Scale, Proportion and Quantity

Progression Across the Grades
In grades pre-K–2, students can use relative scales (e.g., bigger and smaller, hotter and colder, faster and slower) to describe objects. They use standard units to measure length.
In grades 3–5, students can recognize that natural objects and observable phenomena exist from the very small to the immensely large. They use standard units to measure and describe physical quantities such as weight, time, temperature, and volume.
In grades 6–8, students can observe time, space, and energy phenomena at various scales, using models to study systems that are too large or too small. They understand phenomena observed at one scale may not be observable at another scale, and the function of natural and designed systems may change with scale. They use proportional relationships (e.g., speed as the ratio of distance traveled to time taken) to

gather information about the magnitude of properties and processes. They represent scientific relationships through the use of algebraic expressions and equations.
In grades 9–12, students can understand that the significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. They recognize that patterns observable at one scale may not be observable or exist at other scales, and some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly. Students use orders of magnitude to understand how a model at one scale relates to a model at another scale. They use algebraic thinking to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).

4. Systems and System Models

Progression Across the Grades
In grades pre-K–2, students can understand that objects and organisms can be described in terms of their parts and that systems in the natural and designed world have parts that work together.
In grades 3–5, students can understand that a system is a group of related parts that make up a whole and can carry out functions its individual parts cannot. They can also describe a system in terms of its components and their interactions.
In grades 6–8, students can understand that systems may interact with other systems; they may have sub-systems and be a part of larger complex systems. They can use models to represent systems and their interactions—such as inputs, processes, and outputs—and energy, matter, and information flows within systems. They can also learn that models are limited in that they only represent certain aspects of the system under study.
In grades 9–12, students can investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They can use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. They can also use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models. They can also design systems to do specific tasks.

5. Energy and Matter: Flows, Cycles, and Conservation

Progression Across the Grades
In grades pre-K–2, students can observe that objects may break into smaller pieces, be put together into larger pieces, or change shapes.
In grades 3–5, students can learn that matter is made of particles and energy can be transferred in various ways and between objects. Students observe the conservation of matter by tracking matter flows and cycles before and after processes and recognizing that the total weight of substances does not change.
In grades 6–8, students can learn that matter is conserved because atoms are conserved in physical and chemical processes. They also learn that, within a natural or designed system, the transfer of energy drives the motion and/or cycling of matter. Energy may take different forms (e.g., energy in fields, thermal energy, energy of motion). The transfer of energy can be tracked as energy flows through a designed or natural system.
In grades 9–12, students can learn that the total amount of energy and matter in closed systems is conserved. They can describe changes of energy and matter in a system in terms of energy and matter flows into, out of, and within that system. They also learn that energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems. Energy drives the cycling of matter within and between systems. In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

6. Structure and Function

Progression Across the Grades
In grades pre-K–2, students can observe that the shapes and stability of structures of natural and designed objects are related to their functions.
In grades 3–5, students can learn that different materials have different substructures, which can sometimes be observed, and that substructures have shapes and parts that serve functions.
In grades 6–8, students can model complex and microscopic structures and systems and visualize how their function depends on the shapes, composition, and relationships among its parts. They analyze many complex natural and designed structures and systems to determine how they function. They design structures to serve particular functions by taking into account properties of different materials and how materials can be shaped and used.
In grades 9–12, students can investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal the system's function and/or solve a problem. They infer the functions and properties of natural and designed objects and systems from their overall structure, the way their components are shaped and used, and the molecular substructures of their various materials.

7. Stability and Change

Progression Across the Grades
In grades pre-K–2, students can observe that some things stay the same while other things change, and things may change slowly or rapidly.
In grades 3–5, students can measure change in terms of differences over time, and observe that change may occur at different rates. Students learn some systems appear stable, but over long periods of time they will eventually change.
In grades 6–8, students can explain stability and change in natural or designed systems by examining changes over time, and considering forces at different scales, including the atomic scale. Students learn changes in one part of a system might cause large changes in another part, systems in dynamic equilibrium are stable due to a balance of feedback mechanisms, and stability might be disturbed by either sudden events or gradual changes that accumulate over time
In grades 9–12, students can understand that much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems over very short or very long periods of time. They see some changes are irreversible, and negative feedback can stabilize a system, while positive feedback can destabilize it. They recognize that systems can be designed for greater or lesser stability.

8. Interdependence of Science, Engineering, and Technology

Progression Across the Grades
In grades pre-K–2, students can understand that science and engineering involve the use of tools to observe and measure things.
In grades 3–5, students can describe how science and technology support each other. Tools and instruments are used to answer scientific questions, while scientific discoveries lead to the development of new technologies.
In grades 6–8, students can identify that engineering advances have led to important discoveries in virtually every field of science, and that scientific discoveries have led to the development of entire industries and engineered systems. Science and technology drive each other forward.
In grades 9–12, students can understand that science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise.

9. Influence of Engineering, Technology, and Science on Society and the Natural World

Progression Across the Grades
In grades pre-K–2, students can understand that every human-made product is designed by applying some knowledge of the natural world and is built by using natural materials. Taking natural materials to make things also makes an impact on the environment.
In grades 3–5, students can describe that people's needs and wants change over time, as do their demands for new and improved technologies. Engineers improve existing technologies or develop new ones to increase their benefits, decrease known risks, and meet societal demands. When new technologies become available, they can bring about changes in the way people live and interact with one another.
In grades 6–8, students can understand that all human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment. The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Technology use varies over time and from region to region.
In grades 9–12, students can describe how modern civilization depends on major technological systems, such as agriculture, health, water, energy, transportation, manufacturing, construction, and communications. Engineers continuously modify these systems to increase benefits while decreasing costs and risks. New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

The Nature of Science in Curricula

An additional goal for pre-K–12 STE education is a scientifically and technologically literate person who can understand the nature of scientific knowledge. Indeed, the key consistent characteristic of scientific knowledge across the disciplines is that scientific knowledge itself is open to revision in light of new evidence.

The NRC *Framework* summarizes the nature of science in the following statement:

> Epistemic knowledge is knowledge of the constructs and values that are intrinsic to science. Students need to understand what is meant, for example, by an observation, a hypothesis, an inference, a model, a theory, or a claim and be able to distinguish among them.
>
> NRC, 2012, p. 79

Well-designed curricula should give students the opportunity to develop an understanding of the enterprise of science as a whole. A key challenge for curricula is how to explain both the natural world and what constitutes the formation of adequate, evidence-based scientific explanations. To be clear, this perspective complements but is distinct from students engaging in scientific and engineering practices in order to enhance their knowledge and understanding of the natural world.

The basic understandings about the nature of science include:

1. Scientific investigations use a variety of methods.
2. Scientific knowledge is based on empirical evidence.
3. Scientific knowledge is open to revision in light of new evidence.
4. Scientific models, laws, mechanisms, and theories explain natural phenomena.
5. Science is a way of knowing.
6. Scientific knowledge assumes an order and consistency in natural systems.

7. Science is a human endeavor.
8. Science addresses questions about the natural and material world.

The first four of these understandings are closely associated with practices and the second four with crosscutting concepts. The Nature of Science matrix from NGSS, presented in the two tables below, presents specific nature of science perspectives that can be integrated into curriculum and instruction for each grade span.

Students can also be engaged in learning about the nature of science through study of scientists and their work. Even though specific knowledge about these men and women is not included in the standards and will not be subject to state assessment, students should learn about their lives and discoveries, in order to provide them with greater insight into the real-life work of science and to inspire them to pursue educational and career opportunities in STE fields. By way of example, students should be able to recognize and discuss major scientific figures, such as Niels Bohr, Nicolaus Copernicus, Marie Curie, Charles Darwin, Albert Einstein, Galileo Galilei, Johannes Kepler, Gregor Mendel, Isaac Newton, Louis Pasteur, James Watson, Francis Crick, and Rosalind Franklin.

Conclusion

The utility of crosscutting concepts and nature of science will be realized when curriculum developers and teachers develop lessons, units, and courses that use these themes to tie together the broad diversity of STE core ideas and practices. Doing so can help students organize and make sense of relationships across disciplines and to engage in authentic STE.

[This appendix draws from and is an adaptation of the NGSS, Appendices G, H, and J.]

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Understandings about the Nature of Science (Practices)				
Categories	**Pre-K–2**	**3–5**	**Middle School**	**High School**
Scientific Investigations Use a Variety of Methods	• Science investigations begin with a question. • Scientists use different ways to study the world.	• Science methods are determined by questions. • Science investigations use a variety of methods, tools, and techniques.	• Science investigations use a variety of methods and tools to make measurements and observations. • Science investigations are guided by a set of values to ensure accuracy of measurements, observations, and objectivity of findings. • Science depends on evaluating proposed explanations. • Scientific values function as criteria in distinguishing between science and non-science.	• Science investigations use diverse methods and do not always use the same set of procedures to obtain data. • New technologies advance scientific knowledge. • Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings. • The discourse practices of science are organized around disciplinary domains that share exemplars for making decisions regarding the values, instruments, methods, models, and evidence to adopt and use. • Scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge.
Scientific Knowledge Is Based on Empirical Evidence	• Scientists look for patterns and order when making observations about the world.	• Science findings are based on recognizing patterns. • Scientists use tools and technologies to make accurate measurements and observations.	• Science knowledge is based upon logical and conceptual connections between evidence and explanations. • Science disciplines share common rules of obtaining and evaluating empirical evidence.	• Science knowledge is based on empirical evidence. • Science disciplines share common rules of evidence used to evaluate explanations about natural systems. • Science includes the process of coordinating patterns of evidence with current theory. • Science arguments are strengthened by multiple lines of evidence supporting a single explanation.
Scientific Knowledge Is Open to Revision in Light of New Evidence	• Science knowledge can change when new information is found.	• Science explanations can change based on new evidence.	• Scientific explanations are subject to revision and improvement in light of new evidence. • The certainty and durability of science findings varies. • Science findings are frequently revised and/or reinterpreted based on new evidence.	• Scientific explanations can be probabilistic. • Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. • Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that

Understandings about the Nature of Science (Practices)				
Categories	**Pre-K–2**	**3–5**	**Middle School**	**High School**
				may result in revision of an explanation.
Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena	• Scientists use drawings, sketches, and models as a way to communicate ideas. • Scientists search for cause and effect relationships to explain natural events.	• Science theories are based on a body of evidence and many tests. • Science explanations describe the mechanisms for natural events.	• Theories are explanations for observable phenomena. • Science theories are based on a body of evidence developed over time. • Laws are regularities or mathematical descriptions of natural phenomena. • A hypothesis is used by scientists as an idea that may contribute important new knowledge for the evaluation of a scientific theory. • The term "theory" as used in science is very different from the common use outside of science.	• Theories and laws provide explanations in science, but theories do not, with time, become laws or facts. • 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 validated by the science community 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. • Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory. • Laws are statements or descriptions of the relationships among observable phenomena. • Scientists often use hypotheses to develop and test theories and explanations.

Understandings about the Nature of Science (Crosscutting Concepts)				
Categories	**Pre-K–2**	**3–5**	**Middle School**	**High School**
Science Is a Way of Knowing	• Science knowledge helps us know about the world.	• Science is both a body of knowledge and processes that add new knowledge. • Science is a way of knowing that is used by many people.	• Science is both a body of knowledge and the processes and practices used to add to that body of knowledge. • Science knowledge is cumulative and many people, from many generations and nations, have contributed to science knowledge. • Science is a way of knowing used by many people, not just scientists.	• Science is both a body of knowledge that represents a current understanding of natural systems and the processes used to refine, elaborate, revise, and extend this knowledge. • Science is a unique way of knowing and there are other ways of knowing. • Science distinguishes itself from other ways of knowing through use of empirical standards, logical arguments, and skeptical review. • Science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time.
Scientific Knowledge Assumes an Order and Consistency in Natural Systems	• Science assumes natural events happen today as they happened in the past. • Many events are repeated.	• Science assumes consistent patterns in natural systems. • Basic laws of nature are the same everywhere in the universe.	• Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation. • Science carefully considers and evaluates anomalies in data and evidence.	• 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. • Science assumes the universe is a vast single system in which basic laws are consistent.
Science Is a Human Endeavor	• People have practiced science for a long time. • Men and women of diverse backgrounds are scientists and engineers.	• Men and women from all cultures and backgrounds choose careers as scientists and engineers. • Most scientists and engineers work in teams. • Science affects everyday life. • Creativity and imagination are	• Men and women from different social, cultural, and ethnic backgrounds work as scientists and engineers. • Scientists and engineers rely on human qualities, such as persistence, precision, reasoning, logic, imagination and creativity. • Scientists and engineers are guided by habits of mind, such as intellectual honesty, tolerance of ambiguity, skepticism and openness to new ideas.	• Scientific knowledge is a result of human endeavor, imagination, and creativity. • Individuals and teams from many nations and cultures have contributed to science and to advances in engineering. • Scientists' backgrounds, theoretical commitments, and fields of endeavor influence the nature of their findings. • Technological advances have influenced the progress of science and science has influenced advances in technology. • Science and engineering are influenced by society and society is influenced by science and engineering.

Understandings about the Nature of Science (Crosscutting Concepts)

Categories	Pre-K–2	3–5	Middle School	High School
		important to science.	• Advances in technology influence the progress of science and science has influenced advances in technology.	
Science Addresses Questions About the Natural and Material World	• Scientists study the natural and material world.	• Science findings are limited to what can be answered with empirical evidence.	• Scientific knowledge is constrained by human capacity, technology, and materials. • Science limits its explanations to systems that lend themselves to observation and empirical evidence. • Science knowledge can describe consequences of actions but is not responsible for society’s decisions.	• Not all questions can be answered by science. • Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. • Science knowledge indicates what can happen in natural systems—not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge. • Many decisions are **not** made using science alone, but rely on social and cultural contexts to resolve issues.

Appendix IX
Relevant Contexts for Teaching Science and Technology/Engineering

Science, technology, and engineering influence many aspects of people's lives, and in turn people influence the direction and use of scientific, engineering, and technological endeavors. A real-world context can make a curriculum relevant to students, helping them understand and apply core ideas and practices. It can engage and motivate students to deepen their understanding, apply their learning, build identity as civic participants, communicate their ideas, and prepare for college and careers.

Relevant contexts can be drawn from science, technology, and engineering in society; nature and history of science; cultural and technological perspectives; current issues; community issues; and a variety of professions. Listed below are *examples* of specific contexts or topics that can be used to effectively teach Massachusetts' STE standards. Educators can use one or more of them to design an entire unit, theme, or course. They can be applied to elementary, middle, or high school curricula.

Biotechnology

Biotechnology is a rapidly expanding field that uses a growing set of techniques to derive valuable products from organisms and their cells. Biotechnology is already commonly used to identify potential suspects in crimes or exonerate persons wrongly accused, determine paternity, diagnose diseases, make high-yield pest-resistant crops, and treat genetic ailments. Introducing students to biotechnology as a way of understanding the molecular basis of heredity can highlight the application and importance of related biological concepts and processes. Biotechnology can also provide students with methods and critical thinking skills needed to evaluate the benefits and risks of this technology.

Green Chemistry

Green chemistry provides a framework and lens for learning, teaching, and investigating chemistry concepts. Green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. Introducing students to green chemistry helps them to incorporate chemistry concepts into relevant contexts, particularly when applied to the life cycle of a chemical product, including its design, manufacture, use, and disposal. Green chemistry also gives students opportunities to explain and research how to reduce the negative impacts of chemical products and processes on human health and the environment.

Ocean Literacy

The ocean covers most of the planet, contains important food sources, and regulates the temperature and climate of the globe. Massachusetts is a coastal state: the ocean affects us in many ways, and we affect the ocean. People's actions, such as overfishing, habitat destruction, and actions leading to climate change, have negative effects on the health of the planet and our state. Increasing ocean literacy helps to build a public that can make informed and responsible decisions about their own community. Ocean literacy can help students develop an understanding of the interdisciplinary nature of ocean sciences and build connections between the ocean, its resources, and human actions.

Environmental Literacy/Sustainability

Environmental literacy is focused on a fundamental understanding of the systems of the natural world and the relationships and interactions between the living and non-living environments. It involves the ability to understand scientific evidence and use it to make informed decisions regarding environmental issues, as well as developing and implementing solutions to key challenges. The concept of sustainability comes from the increasing concern that current patterns of human behavior, such as over-consumption and population growth, could lead to negative consequences for the environment, including human populations. Environmental literacy can give students a framework for understanding our natural resources, connected systems, and how to balance environmental needs across communities. It also can provide students with methods to evaluate the various viewpoints on environmental topics so they can think critically about the issues facing the environment.

Forensics

Forensic sciences include any scientific field that is applied to the field of law. Forensics is a necessary factor in criminal investigations, using science to link a crime to its perpetrator. It is an excellent context to show students the diversity of scientific and technical careers, both in the lab and in the field. The interdisciplinary nature of forensics requires students to apply core ideas from different disciplines, critically analyze information, construct explanations based on evidence, and communicate findings.

Clean Energy/Renewable Energy

Clean energy, or renewable energy, has gained increased interest as society's demand for energy increases. Government, industry, and communities are seeking innovative ways to meet their energy needs. Clean energy uses natural sources (e.g., sunlight, geothermal energy, wind) to produce energy such as electricity. From wind to solar to biomass, Massachusetts has increased its diversity of energy resources. Using clean energy to illustrate how STE is interconnected helps students to appreciate the complexities of energy issues. Clean energy provides many different examples of how science, technology, and engineering influence each other and how aspects of each discipline play a role in helping explain and connect concepts, practices, and applications.

Computer Science

Computer science includes a wide variety of applications across many different fields—entertainment, medicine and health care, finance, and astronomy, among many others. Daily changes in technology, communication, and the information life cycle have contributed to the changing face of society and the practice of science and engineering. This is an exciting and creative pursuit, which involves designing and building software; developing effective ways to solve computing problems; collecting and analyzing new and larger data sets; and devising new and better ways of using computing devices, digital tools, and software to address particular challenges, such as robotics, computer vision, or digital forensics.

Nanotechnology

Nanotechnology is the study and application of micro-scale materials being used across all fields of science and technology. Nanotechnology is used to make everything from stain-proof clothing to microfilms to medicine. Nanobots created by engineers who work on a very tiny scale could revolutionize medicine and manufacturing. Curricula focused on nanotechnology can make students aware of how nanotechnology is transforming tools, techniques, and highly advanced products, and engage them in applying core ideas and practices from a variety of disciplines.

Appendix X
The Value of Out of School Time Programming

Out of school time (OST) programming can be an effective complement to school day learning. OST programs can offer opportunities for students to immerse themselves in a variety of STE experiences to gain new skills and knowledge, apply school learning, and develop literacy and fluency in different contexts. OST programs can include before- and after-school programs; weekend and summer (or vacation week) programs and camps; informal learning centers, such as museums, zoos, nature centers, and community gardens; summer learning experiences; or youth clubs and internships that focus on youth development.

Interest and Engagement

STE programming in OST learning environments can capitalize on students' interest about the world in which they live and can offer multiple contexts that promote active engagement. Students can spend more time focused on a science activity or an engineering challenge that is of particular interest to them. Many OST programs offer peer networks that foster sustained participation with students and families. This sustained engagement and freedom within informal, flexible learning time motivates students as they develop mastery and competency with science concepts and practices in OST programs.

Identity

Developing an STE identity involves multiple elements, such as getting young people interested in STE topics and professions, developing competency and a sense of confidence, and getting all youth to envision themselves as potential contributors and participants in this enterprise (NRC, 2012). OST programming that provide students with STE mentors or opportunities to engage with STE professionals allows them to build relationships and develop their ideas about the types of people who work in these fields. STE professionals serve as role models whom students can ask questions about how they became interested in their career, what happens on a daily basis in their work, and how they contribute to their community. Such experiences can be particularly beneficial to girls' perceptions and career goals (Tan et al., 2013).

Relevance

OST programming that offers STE experiences can also increase students' awareness of the relevance of science in their lives and prepare them for active citizenship with compelling local, regional, or global issues, such as energy resources, water quality, invasive organisms, and erosion. These experiences can give students a chance to spend more time investigating phenomena, problems, and solutions than they can during the school day. Strategies that involve the community underscore the importance of connecting the school science curriculum to students' lives and the community in which they live. It is through such connections that students who may traditionally be alienated from science recognize science as relevant to their lives and future and deepen their understanding of STE concepts and practices (NRC, 2015). The community context for science education capitalizes on community resources and makes science more culturally, linguistically, and socially relevant for diverse student groups (González et al., 2005). Students can develop critical consciousness of social inequity especially as such inequities exist in their communities. STE experiences in OST programs can contribute to students' awareness and understanding of the connection and value of STE in addressing and solving societal issues.

Career and Life Skills

OST programs can offer students essential life and career skills, such as working in teams and communicating ideas to a variety of audiences. Students who interact with STE professionals are more aware of career paths and options, as well as an understanding of what these potential jobs entail. OST programs often provide STE field trips that engage students in a variety of activities and offer different perspectives on science, technology, and engineering skills and careers.

Schools and teachers are a critical part of students' STE education, but are only one part of a larger system of what students need to achieve success in K–12 and beyond. OST programs that strive to enhance STE learning opportunities for all students focus on creating engaged young citizens who can contribute to a dynamic and dexterous workforce and develop the capacity and competencies needed to contribute to their community and the innovation economy. What happens outside school can be equally as important as what happens in school in setting a child's direction, activating their interest, and developing their understanding of the role of STE in their dynamic world (Noam et al., 2013).

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Appendix XI
Safety Practices and Legal Requirements

Safe practices are integral to teaching and learning of STE at all levels. It is the responsibility of each district to provide safety information and training to educators and students and the responsibility of each educator to understand and implement safe laboratory practices. This section describes the laboratory safety practices that are required by law, as well as resources that provide guidance on general safety practices.

Duty of Care of Adults Teaching Science

As professionals, teachers of science have a duty of care to ensure the safety of students, teachers, and staff. ("Duty of care" is defined as an obligation, recognized by law, requiring conformance to a certain standard of conduct to protect others against unreasonable risk.) Accordingly, a science educator must act as a reasonably prudent person would in providing and maintaining a safe learning environment for students.[*]

A reasonably prudent teacher:

- Provides prior warning of any hazards associated with an activity.
- Demonstrates the essential portions of the activity.
- Provides active supervision.
- Provides sufficient instruction to make the activity and its risks understandable.
- Ensures that all necessary safety equipment is available and in good working order.
- Has sufficient training and equipment available to handle an emergency.
- Ensures that the place of the activity is as safe as reasonably possible.[†]

Additionally, a science teacher must be able to provide an educational justification for engaging in any activity associated with an inherent safety risk.

Legal Aspects of Laboratory Safety

Educators should be aware of the legal framework outlined below in planning for the design, construction, and implementation of science instruction, classrooms and laboratories:

Applicable Massachusetts Law

1. **Safety Goggles**
   Wearing protective goggles in school laboratories is required by Massachusetts law. Mass. Gen. Laws c. 71, § 55C, states:

   > Each teacher and pupil of any school, public or private, shall, while attending school classes in industrial art or vocational shops or laboratories in which caustic or explosive chemicals, hot liquids or solids, hot molten metals, or explosives are used or in which welding of any type, repair or servicing of vehicles, heat treatment or tempering of

[*] National Science Teachers Association (NSTA). (2007). *NSTA position statement: Liability of science educators for laboratory safety*. Retrieved from www.nsta.org/docs/PositionStatement_Liability.pdf
[†] Maryland Department of Education. (1999). Legal aspects of laboratory safety. In *Science safety manual.* Retrieved from mdk12.msde.maryland.gov/instruction/curriculum/science/safety/legal.html

> metals, or the milling, sawing, stamping or cutting of solid materials, or any similar dangerous process is taught, exposure to which may be a source of danger to the eyes, wear an industrial quality eye protective device, approved by the department of public safety. Each visitor to any such classroom or laboratory shall also be required to wear such protective device.

Thus, all individuals in the laboratory are required to wear goggles if they are using any of the materials or procedures listed in the statute. It is critically important for teachers to make students aware of the hazards of working with chemicals and open flame in the laboratory and other settings and to be sure they wear goggles to protect their eyes. (Wearing protective goggles is also an Occupational Safety and Health Administration [OSHA] standard—1910.133.)

2. Treatment of Animals

<u>Animals should be treated with care and dissection should be confined to the classroom and undertaken for academic purposes</u>.

Mass. Gen. Laws c. 272, § 80G, states:

> No school principal, administrator or teacher shall allow any live vertebrate to be used in any elementary or high school under state control or supported wholly or partly by public money of the state as part of a scientific experiment or for any other purpose in which said vertebrates are experimentally medicated or drugged in a manner to cause painful reactions or to induce painful or lethal pathological conditions, or in which said vertebrates are injured through any other type of treatment, experiment or procedure including but not limited to anesthetization or electric shock, or where the normal health of said animal is interfered with or where pain or distress is caused.
>
> No person shall, in the presence of a pupil in any elementary or high school under state control or supported wholly or partly by public money of the state, practice vivisection, or exhibit a vivisected animal. Dissection of dead animals or any portions thereof in such schools shall be confined to the classroom and to the presence of pupils engaged in the study to be promoted thereby, and shall in no case be for the purpose of exhibition.
>
> Live animals used as class pets or for purposes not prohibited in paragraphs one and two hereof in such schools shall be housed or cared for in a safe and humane manner. Said animals shall not remain in school over periods when such schools are not in session, unless adequate care is provided at all times.
>
> The provisions of the preceding three paragraphs shall also apply to any activity associated with or sponsored by the school.
>
> Whoever violates the provisions of this section shall be punished by a fine of not more than one hundred dollars.

For further discussion on the Board of Education's policy on the dissection of animals, please consult Appendix XII.

3. "Right to Know"

<u>People who work with hazardous chemicals have a "right to know" the dangers and nature of these chemicals</u>.

Mass. Gen. Laws c. 111F, § 7(a), states:

> Except as otherwise provided by this section, an employer shall label with the chemical name each container in his or her workplace containing a toxic or hazardous substance. Said label shall also contain the proper NFPA [National Fire Protection Association] Code applicable to any contents of the container for which an NFPA Code has been published in NFPA 49, Hazardous Chemical Data, but only in those instances where the

> container contains more than five gallons or thirty pounds of materials to which the NFPA Code is applicable.

Thus, laboratory managers must make sure that all posters, labels, Safety Data Sheets (SDSs), etc., describing and explaining the dangers of hazardous chemicals are clearly displayed and current.

4. **Mercury**
   Schools are not to have mercury, including equipment or materials containing mercury, on the premises (with limited exceptions), and any mercury-added products must be disposed of appropriately.
   Mass. Gen. Laws c. 21H, § 6G (as amended by Chapter 190 of the Acts of 2006, effective October 1, 2006), states:

> No school in the commonwealth shall purchase for use in a primary or secondary classroom elemental mercury, mercury compounds or mercury-added instructional equipment and materials, except measuring devices and thermometers for which no adequate nonmercury substitute exists that are used in school laboratories. This section shall not apply to the sale of mercury-added lamps or those products whose only mercury-added component is a mercury-added lamp or lamps.

Mass. Gen. Laws c. 21H, § 6I (as amended by Chapter 190 of the Acts of 2006, effective May 1, 2008), states:

> (a) No person, household, business, school, healthcare facility or state or municipal government shall knowingly dispose of a mercury-added product in any manner other than by recycling, disposing as hazardous waste or using a method approved by the department [of environmental protection].

Relevant Federal Law

1. **Americans with Disabilities Act (ADA)**
   Public schools are required to comply with provisions of the ADA. Students with disabilities are entitled to a level of laboratory experience appropriate to them as individuals. The ADA was amended in 2008 to allow for coverage of a broad range of disabilities, including allergies that would substantially impair a major life activity in the absence of mitigating factors. As a result, teachers must take additional precautions to ensure that reasonable accommodations are made for students who are allergic to materials used in the science lab (see “Additional Resources” for guidance on latex allergies).

2. **Occupational Safety and Health Administration (OSHA)**
   The Occupational Safety and Health Act requires that certain precautions be observed and certain actions taken to protect the health and safety of employees on the job. Although students are not covered by OSHA, the prudent teacher will conduct the science classroom in such a manner that the regulations are followed by all occupants. Following OSHA precautions for all classroom or laboratory occupants is good safety practice. The following topics are of heightened relevance to science teachers:

   - Limiting the exposure to hazardous chemicals (1910.1450) (www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10106)
     - Laboratory managers should have a chemical hygiene plan, ensure that the proper protective gear is used, provide training for those working in the laboratory, etc.

- Limiting the exposure to blood-borne pathogens (1910.1030) (www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10051)
    - Laboratory managers should have an exposure control plan; provide hand washing facilities; ensure that lab workers wash hands right after the removal of gloves; dispose of contaminated needles and other sharp instruments in puncture-proof, non-leak containers; prohibit the application of cosmetics, changing of contact lenses, and other such practices in the laboratory; provide proper protective eye, hand, and face equipment, etc.
- Providing information about the hazardous chemicals in use in the laboratory (1910.1200) (www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10099)
    - 1910.1200(b)(1): All employers must "provide information to their employees about the hazardous chemicals to which they are exposed, by means of a hazard communication program, labels and other forms of warning, safety data sheets, and information and training."
- Using hand protection when handling potentially dangerous substances (1910.138) (www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9788)
    - 1910.138(a): "Employers shall select and require employees to use appropriate hand protection when employees' hands are exposed to hazards such as those from skin absorption of harmful substances; severe cuts or lacerations; severe abrasions; punctures; chemical burns; thermal burns; and harmful temperature extremes."
    - 1910.138(b): "Employers shall base the selection of the appropriate hand protection on an evaluation of the performance characteristics of the hand protection relative to the task(s) to be performed, conditions present, duration of use, and the hazards and potential hazards identified."

3. Restrictions on Use of Migratory Birds

<u>Individuals are not allowed to acquire live or dead migratory birds, nests, or eggs, or to use them as lab animals</u>.

Under federal law, 16 U.S.C. § 703(a) states:

> [I]t shall be unlawful at any time, by any means or in any manner, to pursue, hunt, take, capture, kill, attempt to take, capture, or kill, possess, offer for sale, sell, offer to barter, barter, offer to purchase, purchase, deliver for shipment, ship, export, import, cause to be shipped, exported, or imported, deliver for transportation, transport or cause to be transported, carry or cause to be carried, or receive for shipment, transportation, carriage, or export, any migratory bird, any part, nest, or eggs of any such bird, or any product, whether or not manufactured, which consists, or is composed in whole or part, of any such bird or any part, nest, or egg thereof, included in the terms of the conventions between the United States and Great Britain for the protection of migratory birds concluded August 16, 1916 (39 Stat. 1702)

Thus, it is illegal to acquire any migratory bird, whether alive or dead, or their eggs or nests, for any purpose, including for use within a classroom or lab.

Additional Resources

1. **General Safety Advice**
   Several websites provide lists of general safety guidelines. (While these practices are commonly accepted, they are not officially endorsed by the Massachusetts Department of Education.)

   - National Science Teachers Association (NSTA), *Position Statement: Safety and School Science Instruction*, www.nsta.org/about/positions/safety.aspx
   - The Council of State Science Supervisors' safety website, www.csss-science.org/safety.shtml
   - Connecticut State Department of Education, *Connecticut High School Science Safety*, www.sde.ct.gov/sde/cwp/view.asp?a=2663&q=334760
   - Connecticut State Department of Education, *Connecticut Middle School Science Safety*, www.sde.ct.gov/sde/cwp/view.asp?a=2663&q=334736
   - Ward's Science, www.wardsci.com/store/content/externalContentPage.jsp?path=/www.wardsci.com/en_US/teacher_resources_safety_data_sheets.jsp
   - Carolina Biological, www.carolina.com/teacher-resources/lab-science-classroom-safety-information/10856.co?N=516766767&Nr=&nore=y
   - Flinn Scientific, www.flinnsci.com/teacher-resources/safety/
   - Laboratory Safety Institute, www.labsafetyinstitute.org/Resources.html
   - National Institutes of Health, www.nih.gov/research-training/safety-regulation-guidance
   - OSHA, www.osha.gov

2. **Special Considerations for the Collection, Handling, and Analysis of Human Biological Material**
   - Safe collection and handling of samples:
     - The Centers for Disease Control and Prevention's (CDC's) Universal Precautions for preventing transmission of bloodborne infections, as well as federal regulations at 29 CFR § 1910.1030, must be followed when human samples are used in laboratories:
       - www.cdc.gov/niosh/topics/bbp/universal.html
       - www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=10051
     - In addition to the Universal Precautions, teachers using human body samples should take the following precautions:
       - Students must be allowed to collect samples only with the supervision and advice of the teacher.
       - Samples must be handled with plastic or latex gloves, chemical splash safety goggles, and a laboratory coat or apron.

- Students must always wash their hands after any laboratory activity involving human body samples.[‡]

- Privacy considerations:
  - The federal Family Educational Rights and Privacy Act (FERPA) protects the privacy of student education records in general, including all of the medical information they contain (20 U.S.C. § 1232g; 34 CFR § 99). Under FERPA, schools must grant parents and eligible students the right to access student records, and must obtain consent before disclosing records. Schools must be mindful of FERPA requirements in developing policies for the handling of student medical information collected in science laboratory activities. For more information on FERPA, visit familypolicy.ed.gov.

3. Safe Handling of Plants and Animals in General

- Institute for Laboratory Animal Research, *Principles and Guidelines for the Use of Animals in Precollege Education*, www.nabt.org/websites/institution/File/Principles%20and%20Guidelines%20for%20the%20Use%20of%20Animals%20in%20Precollege%20Education.pdf
- National Academy of Sciences, *Guide for the Care and Use of Laboratory Animals: Eighth Edition (2011)*, www.nap.edu/catalog/12910/guide-for-the-care-and-use-of-laboratory-animals-eighth
- MSPCA-Angell Headquarters, *Classroom Pets: The Humane Way*, www.mspca.org/cruelty_prevention/classroom-pets-the-humane-way-2/
- American Association for Laboratory Animal Science, *Use of Animals in Precollege Education*, www.aalas.org/about-aalas/position-papers/use-of-animals-in-precollege-education#.Voqeg7YrKUk
- Massachusetts Executive Office of Health and Human Services, Department of Public Health, *Animals in the Classroom: Recommendations for Schools*, www.mass.gov/eohhs/docs/dph/com-health/school/rabies-prtcl-school.pdf
- Oregon Zoo, *Animals in the Classroom*, www.oregonzoo.org/sites/default/files/downloads/Animals%20in%20the%20Classroom_OregonZoo_0.pdf
- Massachusetts Executive Office of Health and Human Services, Department of Public Health, *Guidelines for Safe Handling of Owl Pellets*, www.mass.gov/eohhs/docs/dph/cdc/owl-pellet-handling-guidelines.pdf
- Massachusetts Executive Office of Energy and Environmental Affairs, *Massachusetts Prohibited Plant List*, www.mass.gov/eea/agencies/agr/farm-products/plants/massachusetts-prohibited-plant-list.html
  - *Elodea densa* is a restricted plant. For a permit to have the plant in your classroom, you must complete and submit the permit request form. Contact Trevor Battle (trevor.battle@state.ma.us) for this form.
  - Note also that *Elodea canadensis* is a similar species that is not on the prohibited plant list and is available for sale from biological supply catalogs.

[‡] Maryland Department of Education. (1999). Biology and environmental science: Recognizing and controlling hazards. In *Science safety manual.* Retrieved from mdk12.msde.maryland.gov/instruction/curriculum/science/safety/hazards.html

- Massachusetts Introduced Pest Outreach Project, massnrc.org/pests/factsheets.htm
    - U.S. Department of Agriculture, Animal and Plant Health Inspection Service, letter to teachers and educators about giant African land snails, massnrc.org/pests/linkeddocuments/snail.doc
- Massachusetts Division of Marine Fisheries, *Special License Application* (see the "Scientific Collectors License" section), www.mass.gov/eea/docs/dfg/dmf/commercialfishing/specialapp.pdf

4. Bird Carcasses

Teachers should not take bird carcasses found in the environment and use them for lab work. This practice spreads bird-borne diseases. For more information, check the following websites:

- Massachusetts Department of Public Health, *Frequently Asked Questions about Avian Flu*, www.mass.gov/eohhs/docs/dph/cdc/flu/avian-faq.pdf
- CDC, *Birds Kept as Pets*, www.cdc.gov/healthypets/pets/birds.html

5. Safety Contract Examples

- *Flinn Scientific's Student Safety Contract*, www.flinnsci.com/Documents/miscPDFs/Safety_Contract.pdf
- American Chemical Society, *Student Laboratory Code of Conduct for Secondary Science Program*, www.acs.org/content/acs/en/about/governance/committees/chemicalsafety/chemical-safety-in-the-classroom.html

6. Safe Handling of Chemicals

- Massachusetts Department of Environmental Protection, *Massachusetts School Chemical Management Program*, www.mass.gov/eea/docs/dep/service/schlchem.pdf
- U.S. Consumer Safety Product Commission and National Institute for Occupational Safety and Health, *School Chemistry Laboratory Safety Guide*, www.cdc.gov/niosh/docs/2007-107/pdfs/2007-107.pdf
- American Chemical Society, *Chemical Safety in the Classroom*, www.acs.org/content/acs/en/about/governance/committees/chemicalsafety/chemical-safety-in-the-classroom.html
- Massachusetts Department of Environmental Protection, *Mercury*, www.mass.gov/eea/agencies/massdep/toxics/sources/mercury.html

7. Allergies

Teachers should be aware that students may be allergic to latex, a material commonly found in balloons and laboratory gloves. For information on latex allergies, check the following resources:

- *American Family Physician* article on latex allergy, www.aafp.org/afp/980101ap/reddy.html
- UK Health and Safety Executive site, www.hse.gov.uk/
- American Latex Allergy Association article, latexallergyresources.org/articles/js-online-article-balloons-busted

- Balloon Council site, www.balloonhq.com/BalloonCouncil/facts.html

8. Choking Hazards

Some materials commonly used in science labs and lessons (for example, latex balloons) may pose choking hazards for small children. Teachers should be aware of the risks posed by these materials and take necessary precautions to prevent choking. See HealthyChildren.org for more information: www.healthychildren.org/English/health-issues/injuries-emergencies/Pages/Choking-Prevention.aspx

9. Electricity

When electricity is used in experiments, students must be warned of risk of shock, even when voltage is low.

Electrostatic generators. The Maryland Department of Education's *Science Safety Manual*[§] states that:

> Electrostatic generators used in demonstrations of static electricity produce high voltages (about 10^5 volts) with very low currents. The danger of these generators depends on their size and capacity to produce enough current to be dangerous. In many cases the shock from such devices is very quick and not harmful. The startling effect, however, can be detrimental to persons with heart conditions.
>
> In general, experiments that use human subjects to demonstrate the effect of electrical shock should not be attempted due to the large variation in physical and physiological factors. Leyden jars—which can be charged with electrostatic generators—are especially dangerous because of their capacity to store a charge for long periods of time. An accidental discharge through a person can be avoided by properly shorting the devices after use.

The following resources provide additional information:

- Nuffield Foundation, *Van de Graaff Generator Safety,* www.nuffieldfoundation.org/practical-physics/van-de-graaff-generator-safety
- Science Hobbyist, *(VandeGraaff) Electrostatic Machine Safety,* amasci.com/emotor/safe.html
- Science Hobbyist, *Electrostatic and VandeGraaff Generators: Solving Humidity Problems,* amasci.com/emotor/humid.html

Sample Safety Guidelines

Science staff should actively work to set safety policies, expectations, and classroom practices for their school and district. Example safety guidelines for the science classroom are included on the following pages. This example is excerpted from the Council of State Science Supervisors' *Science and Safety: It's Elementary*, found at www.csss-science.org/safety.shtml. This is not necessarily a definitive list, nor does it constitute a definitive safety policy. It is included as an example for discussion and illustration.

[§] Maryland Department of Education. (1999). Physics: Balancing creativity and safety. In *Science safety manual.* Retrieved from http://mdk12.msde.maryland.gov/instruction/curriculum/science/safety/physics.html

1. Where can I find a general science safety checklist?

General Items

The following practices should be observed in your science instructional environment.

1. **Have and enforce** a safety contract signed by students and parents.
2. **Identify** medical and allergy problems for each student to foresee potential hazards.
3. **Assess and minimize** barriers for students with disabilities.
4. **Model, post, and enforce** all safety procedures. Display safety posters and the numbers for local poison control centers and emergency agencies.
5. **Know** district and state policies concerning administering first aid and have an adequately stocked first-aid kit accessible at all times.
6. **Report** all injuries, including animal scratches, bites, and allergic reactions, immediately to appropriate personnel.
7. **Be familiar with** your school's fire regulations, evacuation plans, and the location and use of fire fighting equipment.
8. **Post and discuss** emergency escape and notification plans/emergency phone numbers in each space used for science activity.
9. **Make certain** that the following items are easily accessible in elementary classrooms, classrooms with labs, and science resource rooms:
   - appropriate-size chemical splash goggles that are American National Standards Institute (ANSI) Z87 or Z87.1 coded and of type G, H, or K only
   - non-allergenic gloves
   - non-absorbent, chemical-resistant protective aprons
   - eyewash units
   - safety spray hoses/shower
   - ABC tri-class fire extinguisher(s)
   - flame retardant treated fire blanket
10. **Make certain** that you, your students, and all visitors are adequately protected when investigations involving glass (not recommended), heat, chemicals, projectiles, or dust-raising materials are conducted.
11. **Implement** a goggle sanitation plan for goggles used by multiple classes.
12. **Keep** spaces where science activities are conducted uncluttered.
13. **Limit** size of student working groups to a number that can safely perform the activity without causing confusion and accidents.
14. **Prepare** records [including Material Safety Data Sheets (MSDS) (See question 5) on all chemicals used] on safety training and laboratory incidents.
15. **Provide** adequate workspace (45 square feet) per student as well as low table sections for wheelchair accessibility that can be supervised by recommended ratio of teacher to student of 1:24.
16. **Do not permit** eating and drinking in any space where science investigations are conducted.
17. **Do not store,** under any circumstances, chemicals and biological specimens in the same refrigerator used for food and beverages.
18. **Do not use** mercury thermometers with elementary students, since their use is inappropriate. Any mercury thermometers still present should be disposed of properly.

Glassware Precautions

19. **Substitute** plasticware for glassware in elementary classrooms, classrooms with labs, and science resource rooms.
20. **Possess** a whiskbroom, dust pan, and disposal container for broken glass when using glassware of any type (not recommended).
21. **Make certain** that students understand they are not to drink from glass/plasticware used for science experiments.

Chemical Precautions

22. **Label** equipment and chemicals adequately with respect to hazards and other needed information.
23. **Store** chemicals in appropriate places: e.g., in secured cabinet or stockroom, at or below eye level, on wooden shelves with a front lip, and without metal supports. Storage space should be kept cool, dry, and locked.
24. **Make certain** that students understand that chemicals must never be mixed "just for fun" or "to see what might happen"; that they should never taste chemicals; and that they should always wash their hands after working with chemicals.

Electrical Precautions

25. **Make certain** that students understand that they must NOT perform experiments with electrical current at home or at school "just for fun or to see what will happen." Only supervised activities directed by the teacher should be done.
26. **Make certain** electrical cords are short and plugged into the nearest socket. Emphasize that students grasp the plug, rather than the cord, when unplugging electrical equipment. Cords also must be in good repair. Do not use extensions.
27. **Be sure** that students' hands and surrounding surfaces are dry before plugging in electrical cords or turning on and off switches and appliances/tools. Water can be a good conductor of electricity.
28. **Make sure** all electrical outlets are Ground-Fault Interrupters (GFIs). Cover outlets when not in use.
29. **Use** only three-prong (grounded) plugs when small electrical tools such as heating elements for terraria and aquaria, hot plates, or small motors are used. Extension cords **should not be used**.
30. **Instruct** students never to grasp any electrical device that has just been turned off, since it may be hot after use and result in serious burns.
31. **Make certain** that students understand that connecting only a wire between the terminals of a battery will result in the wire getting hot and possibly causing serious burns.
32. **Remind** students that even non-electrical hand tools such as hammers, screwdrivers, or hand drills slip easily and can produce projectiles or inflict serious cuts. Appropriate safety equipment **should** always **be worn**.

2. Where can I find a checklist of common laboratory operating procedures?

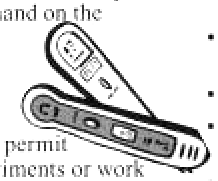
Regulated Safety Rules

- **Know** district, local, and state statutes and regulations regarding animal care, storage of chemicals, and fire safety. Does your district have a written Chemical Hygiene Plan? A district Science Safety Policy?
- **Maintain** Material Safety Data Sheets (MSDS) for all chemical supplies with a second set in the main office; generic chemicals and/or store-bought substances should also be listed in the inventory.
- **Require** the use of American National Standards Institute (ANSI) Z87.1 approved eye protective equipment (typically chemical splash safety goggles—types G, H, or K only), gloves, and aprons during all activities, including demonstrations in which chemicals, glassware, potential projectiles, or heat are used.
- **Dispose** of unwanted chemicals and materials according to state and local regulations.

General Safety Rules

- **Know** the safety hazards before starting an activity; you should do a "dry run" without the students to identify unforeseen hazards.
- **Use** only equipment that is in good working order; inspect equipment before each use.
- **Maintain and have immediate access to** a first-aid kit for emergency treatment (if local and state policies allow), as well as biohazard and chemical spill kits/materials.
- **Never use** unfamiliar chemicals unless MSDS sheets are consulted first. Consult MSDS and the container label before using chemicals for the first time.
- **Never use** mercury thermometers in elementary classroms/labs.
- **Prevent** contamination by not returning unused chemicals to the original container.
- **Label and date** all storage containers of laboratory chemicals and preserved specimens upon receipt. Properly label all secondary chemical and specimen (set-out) containers.
- **Use** unbreakable plastic equipment whenever possible; **maintain** a separate waste container for broken glass; **sweep up** broken glass with dustpan and brush.
- **Check** with school medical personnel at the beginning of the school year to identify student medical conditions such as allergies, epilepsy, etc., and **be prepared** to take appropriate actions.
- **Check** safety manuals for chemical and plant toxicity before use.
- **Tie back** long hair; **secure** loose clothing and dangling jewelry; **do not permit** open-toed shoes or sandals during lab activity. Clothing should cover upper and lower body.
- **Wear** appropriate protective eyewear for chemical and projectile hazards, as well as appropriate lab aprons and gloves.
- **Never permit** eating and drinking in the science classroom/laboratory.
- **Advise** students not to engage in a laboratory activity unless directed by you, and only after safety procedures are discussed and student "plans of action" (in inquiry) are **reviewed and approved**.
- **Have** students wash hands and clean nails directly after coming into contact with animals, plants, soil and water samples, chemical substances, and laboratory/work surfaces. Hands **should always be washed** upon completion of an inquiry activity.
- **Teach** students to pick up and transport a microscope with one hand under the base and one hand on the arm.

Classroom Management



- **Supervise** students at all times. Do not permit students to conduct unauthorized experiments or work unsupervised. Do not make assignments that require students to perform hazardous experiments at home.
- **Maintain** a clear view of all students at all times. Set up science learning centers for single students or small groups that allow easy observation of students. Periodically update and evaluate safety concerns in the centers.
- **Do not block** access to exits, emergency equipment, and utilities with personal items.
- **Have** students participate in determining classroom rules, laboratory safety procedures, and emergency action plans.
- **Do not tolerate** boisterous conduct (horseplay). **Enforce** established rules and procedures immediately and appropriately.
- **Practice** the procedures and rules yourself before expecting students to follow them, so you can identify unforeseen consequences and avoid liability.
- **Discuss** safety concerns with students prior to each laboratory activity and **monitor** students for compliance.
- **Ensure** that sight-impaired students are made familiar with and always use the same area and equipment. These students should be "buddied" with a student who can read instructions (if Braille forms or a tape recorder are not available) and guide him/her to safety in case of emergency.
- **Model** safety procedures prior to an activity and have students practice the procedures before beginning work.
- **Use** student safety contracts; have students and parents **read and sign**.
- **Have** an established procedure for student accident or injury: e.g., student runner, telephone/intercom, accident/injury report to the principal, etc.
- **Lock** science classrooms, cabinets, prep area doors, etc., when not in use; **do not permit** students in chemical/equipment storage rooms.
- **Turn off** gas and electrical equipment and close open containers during a fire drill. Gas, if available in the classroom, should always be turned off at the master valve when not in use.
- **Have** students report all accidents to the classroom teacher.
- **Have** students check the classroom daily for safety hazards.
- **Use** only age-appropriate activities with students.
- **Have** a designated "broken glass" container, if you use equipment made of glass (NOT recommended).
- **Limit** the size of student working groups to a number that can safely perform the activity without causing confusion and accidents.
- **Display** commercial and/or student-made safety posters and classroom safety rules in the classroom.
- **Do not permit** elementary students to dispense chemicals or handle containers of hot liquids. **Discourage** tasting and smelling. When smelling is required, students **should waft** vapors toward their nose using their hand. They **should never inhale** the vapors directly.
- **Dispose of** all waste chemicals properly. There should be separate containers for each solid. Non-hazardous liquids/solutions should be rinsed down the drain one at a time and flushed with plenty of water.
- **Clean up** spills or ice immediately on tables and floor; take appropriate precautions against contamination as needed.
- **Have** students clean up their work areas at the completion of each day's activity, including sinks and floor.

Appendix XII
Dissection and Dissection Alternatives in Science Courses: Policies and Resources for Massachusetts Public Schools

Introduction

This appendix, approved by the Board of Elementary and Secondary Education in October 2005 as a guidance document, is designed to help district and school personnel implement the Board's policy on dissection and dissection alternatives in science courses. It also provides a variety of alternative resources to actual dissection.

State Policy

The Board-approved policy on dissection and dissection alternatives states:

> All public schools that offer dissection as a learning activity should, upon written request by a student's parent or guardian, permit a student who chooses not to participate in dissection to demonstrate competency through an alternative method.

Educators teaching life science consider dissection to be an important educational tool. But dissection should be used with care. When animal dissection is considered, teachers should recognize that there are other experiences (e.g., computer programs) for students who choose not to participate in actual dissections.

Further, as described in Mass. Gen. Laws c. 272, § 80G, and in Appendix XI, dissection should be confined to the classroom: "Dissection of dead animals or any portions thereof in…schools shall be confined to the classroom and to the presence of pupils engaged in the study to be promoted thereby and shall in no case be for the purpose of exhibition." This law covers treatment of animals in school settings (not just dissection). Please refer to Appendix XI for further information concerning the treatment of animals and dissection in the classroom.

Recommendations for School and Districts

1. **Schools should be responsible about both the use of live animals and dissection of dead animals in the classroom.**
   Schools and school districts should ensure that animals are properly cared for and treated humanely, responsibly, and ethically. The National Science Teachers Association's recommendations on how to include live animals and dissection of dead animals in the classroom can be found at www.nsta.org/about/positions/animals.aspx.

2. **Schools should develop clear policies on dissection and dissection alternative activities.**
   Schools and school districts should establish a written policy on courses that include animal dissection. The policy should state that options are available for students who object to dissection activities and that, upon written request by a student's parent or guardian, the school will permit that student to demonstrate competency through an alternative method. The policy should specify the available alternatives and explain how a student can participate in such an alternative.

The teacher, or other school authority, should specify in writing what is expected of the student participating in an alternative activity. The activity itself should allow students to gain the same content knowledge as a dissection activity and should involve a comparable investment of time and effort by the student. The students should be subject to the same course standards and examinations as other students in the course.

The school's policy on dissection and dissection alternatives should be included in the student handbook. The school should also provide a copy of the policy at the beginning of the school year to all teachers of science courses that involve dissection. A sample school policy and sample form letter for parents/guardians are included at the end of this appendix.

3. **Schools should include information about dissection in relevant course descriptions, and should clearly specify dissection alternatives in that information.**
   When the school or school district publishes descriptions of the courses that it offers in the life sciences, the description for each course should specify whether dissection is part of the standard laboratory experience in that course. The course description should also state that alternatives to dissection are available for any student who objects to dissection and whose parent or guardian sends a written request to the school.

Information and Resources

1. **Guidance and position statements from various science organizations**
   - **National Science Teachers Association** (2008), *Position Statement on Responsible Use of Live Animals and Dissection in the Science Classroom*, www.nsta.org/about/positions/animals.aspx
   - **Institute of Laboratory Animal Resources, Institute of Medicine, National Research Council, National Academy of Sciences, National Academy of Engineering** (2004), *Principles and Guidelines for the Use of Animals in Precollege Education,* www.nabt.org/websites/institution/File/Principles%20and%20Guidelines%20for%20the%20Use%20of%20Animals%20in%20Precollege%20Education.pdf
   - **National Association of Biology Teachers** (2008), *Position Statement on the Use of Animals in Biology Education*, www.nabt.org/websites/institution/index.php?p=97

2. **Resources on alternatives to dissection**
   A number of organizations will loan or donate alternatives, such as CD-ROMs (virtual dissections), models, and videos to students and schools. The following organizations have free lending libraries and will help teachers find a suitable alternative to a dissection activity. (Often a security deposit is required, but no charges are incurred unless the items are not returned or are returned damaged. The borrower is responsible for return shipping.) Also available are mobile apps (most requiring a purchase) that allow virtual dissection of a variety of organisms.

   - **The American Anti-Vivisection Society (AAVS)**
     800-729-2287
     www.animalearn.org/
   - **People for the Ethical Treatment of Animals (PETA)**
     843-771-2394
     www.peta.org/dissection
     PETA donates virtual dissection software to schools and teachers and offers free professional development training in computer-based dissection.
     Contact Samantha Suiter for more information: SamanthaS@peta.org

- **The Ethical Science and Education Coalition (ESEC)**
  617-523-6020
  www.neavs.org/resources/index.htm
  This Boston-based organization can provide teacher training.
- **The National Anti-Vivisection Society (NAVS)**
  312-427-6065
  Dissection hotline: 800-922-FROG (3764)
  Overview of BioLEAP, NAVS' Biology Education Advancement Program:
  www.navs.org/education/animals-in-education
  Free online dissection resources: www.navs.org/education/free-online-dissection-resources
  Dissection alternatives lending library: www.navs.org/document.doc?id=5

The following websites offer free alternatives to dissection:

- **Various simulations, experiments, and animals**
  (www.animalearn.org/sbDownloads.php#.VqaMIvkrLGg)
- **Frog**
  - Virtual frog dissection kit (froggy.lbl.gov/)
  - Net frog (frog.edschool.virginia.edu/Frog2/)
  - Virtual frog lab (www.mhhe.com/biosci/genbio/virtual_labs/BL_16/BL_16.html)
  - Biology Junction (www.biologyjunction.com/frog_dissection.htm)
- **Fish**
  - Perch dissection (www.bio200.buffalo.edu/labs/tutor/Perch/Perch.html)
  - Perch dissection images (jb004.k12.sd.us/MY%20WEBSITE%20INFO/BIOLOGY%202/ANIMAL%20KINGDOM/PERCH%20DISSECTION/PERCH%20DISSECTION%20HOMEPAGE.htm)
  - Blue mackerel dissection (australianmuseum.net.au/Dissection-of-a-Blue-Mackerel-Scomber-australasicus)
  - Virtual shark lab (www.pc.maricopa.edu/Biology/ppepe/BIO145/lab04.html)
- **Rat**
  - Rat anatomy review (www.utm.edu/staff/rirwin/public_html/ratanat.htm)
  - Kansas State University (www.k-state.edu/organismic/rat_dissection.htm)
  - University of Manitoba (umanitoba.ca/science/biological_sciences/BIOL1030/Lab4/biolab4_2.html#Rat1)
- **Pigeon**
  - Vertebrate anatomy pigeon dissection (www.savalli.us/BIO370/Anatomy/7.Pigeon.html)
  - Pigeon dissection images (jb004.k12.sd.us/MY%20WEBSITE%20INFO/BIOLOGY%202/ANIMAL%20KINGDOM/PIGEON%20DISSECTION/PIGEON%20DISSECTION%20HOMEPAGE.htm)

- SUNY Buffalo's virtual pigeon dissection (www.bio200.buffalo.edu/labs/tutor/Pigeon/Pigeon.html)

- **Fetal pig**
  - Whitman College (www.whitman.edu/biology/vpd/)
  - ZeroBio (www.execulink.com/~ekimmel/fetal0.htm)
  - Biology Corner (www.biologycorner.com/pig/fetal.html)
  - Interactive science activity (carolinascienceonline.com/index.php/resources/fetal_pig_anatomy_interactive_science_activity.html#.Vpa9CPkrLIX0)
- **Cat**
  - Anatomy Corner (anatomycorner.com/main/virtual-cat-dissection/)
  - Cat dissection images (http://www.3dtoad.com/dissections_cat.php)
  - D.R. Adams interactive programs for veterinary anatomy (www.tabanat.com/)
- **Invertebrates**
  - Dissection of a deer tick (www.ent.iastate.edu/imagegal/ticks/iscap/tickdissection/)
  - SUNY Buffalo's virtual crayfish dissection (wwwbio200.nsm.buffalo.edu/labs/tutor/Crayfish/)
  - The Crayfish Corner (www.mackers.com/crayfish/)
- **Owl pellet**
  - Kidwings virtual owl pellet dissection (kidwings.com/nests-of-knowledge/virtual-pellet/)
- **Cow eye**
  - Exploratorium's cow's eye dissection (www.exploratorium.edu/learning_studio/cow_eye/index.html)
- **Brain and heart**
  - Exploratorium's sheep brain dissection: the anatomy of memory (www.exploratorium.edu./memory/braindissection/index.html)
  - Michigan State University atlas of the sheep brain (www.msu.edu/~brains/brains/sheep/index.html)
  - Comparative mammalian brain collections (www.brainmuseum.org)
  - Veterinary gross anatomy online lab (cal.vet.upenn.edu/projects/neurology/lab2/lab2.htm)
  - The Virtual Heart's cardiac anatomy (thevirtualheart.org/anatomyindex.html)

The websites below list many dissection alternatives but are intended for information only. Teachers who identify an item in one of these databases that they want to borrow or purchase should contact the free lending libraries listed above.

- Norina (oslovet.veths.no/NORINA/)
- InterNICHE (www.interniche.org/en)

- The Physicians Committee for Responsible Medicine (www.pcrm.org/)
- Humane Society Veterinary Medical Association: Alternatives in Education database (www.hsvma.org/alternatives#.VkuBn_mrQUO)
- Froguts Inc. (www.froguts.com/)

A special thanks to the New England Anti-Vivisection Society (www.neavs.org) and PETA (www.peta.org) for providing input to this list of dissection alternative resources.

3. Sample School Policy and Sample Form Letter for Parents/Guardians
A sample school policy and a sample form letter for parents/guardians are provided on the following pages.

Sample School Policy

POLICY ON DISSECTION AND DISSECTION ALTERNATIVES

In accordance with the 2005 Board of Elementary and Secondary Education's Policy on Dissection and Dissection Alternatives, our school/school district has developed the following policy.

Participation in hands-on science is important to learning science, and dissections are a valuable learning experience in which all students are encouraged to participate. When dissection is used in the classroom:

- Teachers will thoroughly explain the learning objectives of the lesson and use written and audio-visual materials, as appropriate, to maximize the educational benefits of the experience.
- All specimens will be treated with respect.
- All students will be informed, prior to the dissection, that they have the option of discussing individual concerns about dissection with the appropriate teacher.
- Upon completion of the dissection, the remains will be appropriately disposed of as recommended by the local board of public health.

The science courses that include dissection also offer dissection alternatives. Upon written request of a student's parent or guardian, our school will permit a student who objects to dissection activities to demonstrate competency through an alternative method.

Currently, our school offers the following courses that include dissection: (*name courses, such as: Biology, Honors Biology, and Anatomy and Physiology*). Specific dissection and dissection alternative activities will be listed on the course syllabi, available to students before enrolling in these courses.

Alternative activities may include models (*name models*) and applications (*name Internet, computer, or mobile device programs*) in place of dissecting (*name organism[s]*).

(Schools may find it easier to provide a chart such as the one below.)

Course	Dissection Activity	Dissection Alternative Activity

The procedure for a student to participate in an alternative activity in place of dissection is as follows:

- The student will notify the science teacher of the student's choice to participate in an alternative activity in place of participating in a dissection.
- The student will submit a written request from his or her parent/legal guardian to the science teacher or to the school principal.
- The student will be provided an alternative activity to be determined by the teacher, who will specify in writing what is expected of the student. Alternative activities will allow students to gain the same content knowledge as the dissection activities and will require a comparable investment of time and effort by the student.
- The student will accept responsibility for completing the alternative activity within the assigned time and is expected to learn the same content knowledge as if the student were performing the dissection activity.
- The student will be subject to the same course standards and examinations as other students in the course.

This policy is included in the student handbook and is also provided at the beginning of each school year to all teachers of science courses that involve dissection.

Sample Parent/Guardian Form Letter

Note: A student's parent/guardian is not required to use a particular form to request that the school provide the student with an alternative to dissection. This sample is provided for the convenience of school personnel and parents/guardians who wish to use it.

Dear _____________________________(Principal or Teacher):

I understand that participation in hands-on science is important to learning science and that dissections are an important component of comprehensive science and life science education. I also understand that alternatives to dissection are available and that, upon written request of a parent/legal guardian, the school will permit a student to demonstrate competency through an alternative method, such as computer simulations and other appropriate research activities. I further understand that students participating in alternative activities instead of dissection are subject to the same course standards and examinations as other students in the course.

I request that my child, ____________________________________, be permitted to demonstrate competency through alternative activities rather than participating in dissection.

Sincerely,

____
Signature of parent or legal guardian

____
Printed name of parent or legal guardian

Date: ____________________________

The Development of Massachusetts' Science and Technology/Engineering Frameworks Since 1995

This *Massachusetts Science and Technology/Engineering Curriculum Framework* is one of seven curriculum frameworks that advance Massachusetts' educational reform in learning, teaching, and assessment. It was created, and revised several times, with the guidance and input of many educators, including teachers and administrators in pre-kindergarten through grade 12 school districts, college and university professors, engineers and scientists in the various domains, and staff from the Department of Elementary and Secondary Education. This section provides a brief overview of the development of the *Framework* over time.

Development of the Standards

1995: Initial Framework

This *Framework* has its origins in two reform initiatives in Massachusetts: the Education Reform Act of 1993 and Partnerships Advancing the Learning of Mathematics and Science (PALMS). The 1993 legislation provided for the establishment of the initial *Science and Technology Framework* and was part of a process to develop frameworks for all academic subjects. From 1992 to 2002, the PALMS Statewide Systemic Initiative was funded by the National Science Foundation in partnership with the state and the Noyce Foundation. A central goal of these initiatives was to develop, disseminate, and implement curriculum frameworks in science and technology as well as in mathematics. The initial *Science and Technology Curriculum Framework* was approved in 1995 and included standards for inquiry and content and grade spans through high school.

2001: Full Revision of the Framework

Because the Education Reform Act requires that frameworks be reviewed and revised periodically, a revision panel was appointed by the Commissioner and the Board of Education in the summer of 1998. The panel examined the standards in the original *Science and Technology Curriculum Framework*, reviewed comments on them from the field including significant input from educators, and re-assessed their appropriateness in order to devise a more coherent organization of concepts and skills through the grade levels. The panel referred to the *Benchmarks for Science Literacy—Project 2061* (AAAS, 1993), data from the Third International Mathematics and Science Study, the *National Science Education Standards* (NRC, 1996), the *Technology for All Americans* Project (ITEA, 1996), results from the 1998 administration of the MCAS Science and Technology tests, and advances in STE.

This version of the *Framework*, for the first time, articulated standards for full-year high school courses in earth and space science, biology, chemistry, introductory physics, and technology/engineering. The *Framework* identified a subset of "core" standards for each course that was designed to serve as the basis for high school MCAS assessments. This *Framework* also reflected a strong emphasis on engineering and the technological systems upon which our society relies. It emphasized the importance of content, removing inquiry from the standards. This version of the *Framework* was approved in May 2001.

2006: Minor Revision of High School Standards and Framework *Update*

The revision of the high school standards in 2006 was undertaken in preparation for the inclusion of STE in the state's Competency Determination policy. In particular, the revised content standards presented a single list of content standards for each course with no differentiation between core and non-core standards, making all standards subject to local and state assessment. Also, a two-year integrated science course in grades 9 and 10 was eliminated. No changes were made to standards for pre-K through grade 8.

A number of updates to the *Framework* were also made at the time. Several Guiding Principles were revised, including additions regarding literacy, high expectations, assessment, and districtwide planning. An appendix was added to relate learning standards across all grade spans to broad topics within each strand. Safety practices and legal regulations were researched and detailed. Also, a second appendix presented the Department of Education's (October 2005) Alternative Dissection Policy and resources (see Appendix XII).

2016: Full Revision of the Framework

In the spring of 2009, Massachusetts started a new revision process. After convening a review panel and reviewing current research, assessment information, and resources, the review panel worked to develop a revision of the STE standards. In July 2011, the National Research Council released the *Framework for K–12 Science Education* (NRC, 2012), a critical first step to the development of the Next Generation Science Standards (NGSS). The NRC *Framework* reflected the most current research on science and student learning of science and it identified the science all K–12 students should know from the perspective of scientists and engineers and the educational research community. Massachusetts joined 26 states to develop the NGSS using the NRC *Framework* as a key resource. Educators from across Massachusetts contributed to public comment during NGSS development, which was released in April 2013. The NGSS and our initial state revision had much in common in terms of structure and key features, but not enough (based on public input) to justify Massachusetts' adoption of the NGSS. Instead, the review panel helped adapt NGSS to meet the needs and expectations of our state. The key features of these standards are outlined in earlier sections of this *Framework;* key features include the integration of science and engineering practices with core ideas, presentation of grade-by-grade standards for pre-K through grade 8, maintenance of introductory high school course options, and increased coherence through progressions of learning across grades. The draft revised standards were made public in December 2013, but not advanced for adoption; this gave districts time to work on several other major change initiatives undertaken in the state's Race to the Top grant. This version of the *STE Framework* was adopted in January 2016.

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