**Subject Matter Knowledge Matrix**

**Science and Technology/Engineering Framework**

Students in Massachusetts must meet rigorous academic standards, which are outlined in the [Massachusetts Curriculum Frameworks](https://www.doe.mass.edu/frameworks/). To do so, they must have access to educators with strong content knowledge and pedagogical skills, the building blocks of effective instructional practice.

In support of this, the [Subject Matter Knowledge Guidelines](https://www.doe.mass.edu/edprep/domains/instruction/smk-guidelines.docx) set forth the content knowledge expectations for educator licensure in Massachusetts. Through these expectations, the Massachusetts Department of Elementary and Secondary Education (DESE) seeks to ensure that educators entering the workforce have sufficient content knowledge in their licensure area to support students in mastering the Massachusetts Curriculum Frameworks.

While the Curriculum Frameworks serve as an anchor, the intent is not that educators should simply know the content included in the Frameworks. Rather, educators must move beyond basic or functional knowledge to a level of fluency or expertise with the academic standards such that they can teach and support students in mastering the content.

The figure below shows a steady progression, not in the amount of information one knows, but in the depth and ability to use that information for a specific purpose. The boxes below the continuum outline some assessments used to determine varying levels of content knowledge. The depth at which the knowledge and application of content knowledge must be demonstrated is dependent on the stage of development for an individual educator (i.e. Basic, Functional, Fluent, or Expert) and/or license type (Provisional, Initial, or Professional).



This worksheet should be completed for licensure programs with Subject Matter Knowledge expectations in the [Science and Technology/Engineering Curriculum Framework](https://www.doe.mass.edu/frameworks/current.html), including:

[ ]  Biology, 8-12

[ ]  Chemistry, 8-12

[ ]  Earth Space Science, 8-12

[ ]  General Science, 1-6

[ ]  General Science, 5-8

[ ]  Physics, 8-12

[ ]  Tech/Engineering, 5-12

**Science and Technology/Engineering Content Progression**

The Science and Technology/Engineering Framework includes the following domains of science: Earth and Space, Life, Physical and Technology/Engineering. All domains of science should be addressed in PK through grade 8.At the high school level, courses may specialize in one or more domains. To view this progression, see [Appendix III of the Science and Technology/Engineering Curriculum Framework](https://www.doe.mass.edu/frameworks/scitech/2016-04.pdf#page=134).

To create a strong vertical progression of learning, educators should have the content knowledge to support PK-12 students in mastering prerequisite and advanced standards. Teachers need to be able to access knowledge from prior grades, and teachers who are aware of later content can make better choices about what to emphasize, what language to use, and what larger contexts to provide for their students. This expectation allows teachers to meet students where they are and prepare them for where they are going.

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| **Instructions*:***Please use the chart below to determine which rows of the matrix should be completed for each license. This content knowledge must either be covered directly through program coursework or screened during the admissions process. For each relevant grade level, list the numbers/abbreviations/titles of the **sponsoring organization’s required courses where the content knowledge is explicitly targeted and coherently addressed**. Then, **briefly describe where in the syllabus the content is covered** (i.e., unit name, week number, objective number). Course identifiers should match those of submitted syllabi and content knowledge for each grade level should not be spread across too many courses.   Please note that the full [Science and Technology/Engineering Curriculum Framework](https://www.doe.mass.edu/frameworks/current.html), including the Guiding Principles which are also available in [Appendix A](#_Appendix_A:_Science) of this document, should be consulted when designing programs to ensure appropriate content coverage and rigor for each licensure field’s grade span. Sponsoring organizations should prioritize content fluency in the grade span for the license while ensuring functional content knowledge in the two grade levels below and above the grade span.  To view this progression by grade span, see [Appendix III of the Science and Technology/Engineering Curriculum Framework](https://www.doe.mass.edu/frameworks/scitech/2016-04.pdf#page=134).  |

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| **License and Grade Span** | **Rows to Complete** |
| General Science, 1-6 | Pre-kindergarten through grade 8 |
| General Science, 5-8 | Pre-kindergarten through grade 8 and High School Earth and Space Science, Physics, Biology and Chemistry |
| Biology, 8-12  | Grades 6-8 Life Science content and High School Biology |
| Chemistry, 8-12  | Grades 6-8 Physical Science content and High School Chemistry |
| Earth and Space Science, 8-12  | Grades 6-8 Earth and Space Science content and High School Earth and Space  |
| Physics, 8-12  | Grades 6-8 Physical Science content and High School Introductory Physics |
| Technology/Engineering, 5-12 | Grades 3-8 Technology/Engineering content and High School Technology/Engineering |

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| **Science and Technology/Engineering Content Progression** | **Course(s) or Screening** |
| *Example Row* | *EDU 101 – Weeks 5-7* |
| **Pre-kindergarten:** Students focus on experiencing and making observations of the world around them. Pre-K students build awareness of the wide variety of natural phenomena and processes in the world around them.* Earth and Space Science: They are beginning to learn about their own environment as they observe plants and animals, the Moon and the Sun, and the daily weather.
* Life Science: 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.
* Physical Science: 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.
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| **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. * Earth and Space Science: 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.
* Life Science: 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.
* Physical Science: 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.
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| **Grade 1:** students have more fluency with language, number sense, and inquiry skills. Grade 1 students begin to understand the power of patterns to predict future events in the natural and designed world.* Earth and Space Science: students 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.
* Life Science: 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.
* Physical Science: 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.
* Technology/Engineering: Students begin to think about how different solutions can be designed to solve problems. They design, and re-design, possible solutions.
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| **Grade 2:** 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. * Earth and Space Science: 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.
* Life Science: Students start to look beyond structures of individual plants and animals to looking at the environment in which plants and animals live as a provider of food, water, and shelter that the organisms need.
* Physical Science: Students use their observation skills gained in earlier grades to classify materials based on similar properties and functions. 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.
* Technology/Engineering: Students gain experience testing different materials, objects, and designs to collect and then analyze data for the purpose of determining which option is the best for a specific function.
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| **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. Students reason and provide evidence to support arguments for the influence of humans on nature and nature on human experience.* Earth and Space Science: students analyze weather patterns and consider humans’ influence and opportunity to impact weather-related events.
* Life Science: they study the interactions between and influence of the environment and human traits and characteristics.
* Physical Science: Students consider the interactions and consequent reactions between objects and forces, including forces that are balanced or not.
* Technology/Engineering: 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.
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| **Grade 4:** Students observe and interpret patterns related to the transfer of matter and energy on Earth, in physical interactions, and in organisms. Each domain relates to the use of matter and energy over time and for specific purposes.* Earth and Space Science: 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.
* Life Science: Students learn that animals’ internal and external structures support life, growth, behavior, and reproduction.
* Physical Science: Students learn about energy—its motion, transfer, and conversion—in different physical contexts.
* Technology/Engineering: They work through the engineering design process, focusing on developing solutions by building, testing, and redesigning prototypes to fit a specific purpose.
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| **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. 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. * Earth and Space Science: Students 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.
* Life Science: Students 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).
* Physical Science: Students build on Grade 2 understanding about matter to deepen their understand of properties, phase change, and the particulate nature of matter. They develop initial understandings of gravity.
* Technology/Engineering: Students consider what “technology” means, explore the history of human invention and innovation, and come to understand design solutions as complex systems.
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| **Grade 6:** The integration of Earth and space, life, and physical sciences with technology/engineering gives 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. Students use models and provide evidence to make claims and explanations about structure-function relationships in different STE domains* Earth and Space Science: Students explore Earth features and processes.
* Life Science: They understand the role of cells and anatomy in supporting living organisms.
* Physical Science: They explore the properties of materials and waves.
* Technology/Engineering: Students begin to use criteria and constraints to inform their designs, and deepen their understanding of how specific materials and tools will best serve specific needs.
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| **Grade 7:** Students 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. 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.* Earth and Space Science: Students gain experience with plate tectonics and interactions of humans and Earth processes.
* Life Science: They explore organism systems to support and propagate life, and ecosystem dynamics.
* Physical Science: Students build on grade 3 and 4 understandings to develop more complex understandings of motion and energy systems.
* Technology/Engineering: They explore key technological systems used by society.
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| **Grade 8** **– Cause and Effect:** 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. 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. * Earth and Space: Students explore the causes of seasons and tides and causes of plate tectonics and weather or climate
* Life Science: They study the role of genetics in reproduction, heredity, and artificial selection
* Physical Science: Students learn how atoms and molecules interact to explain the substances that make up the world and how materials change.
* Technology/Engineering: The focus at this grade is on manufacturing processes and systems.
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| **High School – Earth and Space Science:** The high school Earth and space science standards build from middle school and allow high school 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: * Earth’s place in the universe
* Earth’s systems
* Earth and human activity
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| **High School – Biology:** The high school biology standards build from middle school and allow high school 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
* Ecosystems: interactions, energy, and dynamics
* Heredity: inheritance and variation of traits
* Biological evolution: unity and diversity
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| **High School – Chemistry:** The high school chemistry standards build from middle school physical sciences standards and allow 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. The standards expect students to apply a variety of science and engineering practices to three core ideas of chemistry:* Matter and its interactions
* Motion and stability: forces and interactions
* Energy
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| **High School – Introductory Physics:** The high school introductory physics standards build from middle school and allow high school 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:* Motion and stability: forces and interactions
* Waves and their applications in technologies for information transfer
* Energy
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| **High School –** **Technology/Engineering:** The high school technology/engineering standards build from middle school and allow high school 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
* Materials, tools, and manufacturing
* Technological systems
* Energy and power technologies
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**Science and Technology/Engineering Practices**

The Science and Engineering Practices describe the skills that science educators at all levels should seek to develop in their PK-12 students. This represents a shift from the traditional “scientific method”. 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. They are embedded within the content standards so that as students increasingly engage with the subject matter they grow in scientific maturity and expertise throughout the elementary, middle, and high school years. The progression of the practices by grade band is viewable Appendix I of the [Science and Technology/Engineering Curriculum Framework](https://www.doe.mass.edu/frameworks/current.html).

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| **Instructions*:***Initial licensure program candidates must reach a level of fluent content knowledge in order to be endorsed. They must be able to apply content in a range of contexts and vertically connect content to build students’ knowledge. As such, sponsoring organizations must have at least one course covering the practices at the fluent level. Please list the numbers/abbreviations/titles of the **required courses where all eight practices are explicitly targeted and coherently addressed**. Then, **briefly describe where in the syllabus the practices are covered** (i.e., unit name, week number, objective number). Course identifiers should match those of submitted syllabi.  Please note that all eight Science and Technology/Engineering practices overlap and **should be covered together** rather than being split across multiple courses. |

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| **Science and Technology/Engineering Practices** | **Fluent***Initial* *Licensure*  |
| *Example Row* | *EDU 101 – Weeks 5-7* |
| The National Research Council’s *Framework for K-12 Science Education* identifies eight essential science and engineering practices that outline the skills necessary to engage in scientific inquiry and engineering design. These practices are core to the [Science and Technology/Engineering Curriculum Framework](https://www.doe.mass.edu/frameworks/current.html).  It is necessary to teach all of these practices embedded with content, so students develop an understanding and facility with the practices in appropriate contexts. * Students in grades K-12 should engage in all eight practices over each grade band.
* Practices grow in complexity and sophistication across the grades.
* The eight practices are not separate; they intentionally overlap and interconnect.

 1. Asking questions (for science) and defining problems (for engineering)* Asking questions and defining problems in PK-5 builds on prior experiences and progresses to simple descriptive questions that can be tested and to specifying qualitative relationships.
* Asking questions and defining problems in 6-12 progresses to specifying relationships between variables, clarifying arguments and models, and evaluating empirically testable questions and design problems using models and simulations.

 2. Developing and using models.* Modeling in PK-5 builds on prior experiences and progresses to using, developing, and revising simple models (e.g., diagram, drawing, physical replica, diorama, dramatization, or storyboard) that represent concrete events or design solutions.
* Modeling in 6-12 builds on PK-5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems, and to show relationships among variables between systems and their components in the natural and designed worlds.

 3. Planning and carrying out investigations.* Planning and carrying out investigations to answer questions or test solutions to problems in PK-5 builds on prior experiences and progresses to simple investigations that control variables, which provide data & evidence to support explanations or design solutions.
* Planning and carrying out investigations in 6-12 builds on pre-K-5 experiences and progresses to include investigations that use multiple variables and provide evidence for and test conceptual, mathematical, physical, and empirical models.

 4. Analyzing and interpreting data.* Analyzing data in PK-5 builds on prior experiences and collecting, recording, and sharing observations, and progresses to introducing quantitative approaches to collecting data and conducting multiple trials. When possible and feasible, digital tools should be used.
* Analyzing data in 6-12 builds on PK-5 experiences and includes quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. It progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

 5. Using mathematics and computational thinking.* Mathematical and computational thinking in PK-5 builds on prior experience and recognizing that mathematics can be used to describe the natural and designed worlds 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 6-12 builds on pre-K-5 experiences and includes identifying patterns in large data sets and using mathematical concepts to support explanations and arguments. It 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.

 6. Constructing explanations (for science) and designing solutions (for engineering).* Constructing explanations and designing solutions in PK-5 builds on prior experiences and includes use of evidence and ideas in constructing evidence-based accounts of natural phenomena and designing solutions. It 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 6-12 builds on pre-K-5 experiences and includes constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories. It progresses to constructing and critiquing explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

 7. Engaging in argument from evidence.* Engaging in argument from evidence in PK-5 builds on prior experiences and includes comparing ideas and representations about the natural and designed worlds. It 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 6-12 builds on PK-5 experiences and includes constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed worlds. It 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.

 8. Obtaining, evaluating, and communicating information.* Obtaining, evaluating, and communicating information in PK-5 builds on prior experiences and includes observations and texts to communicate new information. It progresses to evaluating the merit and accuracy of ideas and methods.
* Obtaining, evaluating, and communicating information in 6-12 builds on PK-5 experiences and progresses to evaluating the validity and reliability of claims, methods, and designs.
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# **Appendix A: Science and Technology/Engineering Guiding Principles**

The following principles are philosophical statements that underlie the pre-kindergarten through grade 12 Science and Technology/Engineering Framework standards and resources. The goal of the Guiding Principles is to help educators create relevant, rigorous, and coherent Science and Technology/Engineering programs that support student engagement, curiosity, analytical thinking, and excitement for learning over time. The Guiding Principles are organized to reflect the need for relevance (Principles 1–2), rigor (Principles 3–5), and coherence (Principles 6–9). These principles should guide the design and evaluation of programs in both PK-12 and higher education settings.

**Guiding Principle 1. 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 2. 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 3. 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.

**Guiding Principle 4. 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 5. 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.

**Guiding Principle 6. 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.

**Guiding Principle 7. An effective science and technology/engineering program uses regular assessment to inform student learning, guide instruction, and evaluate student progress.** 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). If teachers understand where their students are in their understanding of core ideas, and anticipate what students’ misconceptions and struggles may be, 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 8. 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. 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:



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 9. 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 program.