NATIONAL ASSOCIATION *of* SCHOLARS

Freedom in education

THE FRANKLIN STANDARDS

Model K-12 State Science Standards

The Franklin Standards

Model K–12 State Science Standards

NATIONAL
ASSOCIATION
of SCHOLARS

420 Madison Avenue, 7th Floor
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Freedom™ in education

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Mission

The National Association of Scholars is an independent membership association of academics and others working to sustain the tradition of reasoned scholarship and civil debate in America's colleges and universities. We uphold the standards of a liberal arts education that fosters intellectual freedom, searches for the truth, and promotes virtuous citizenship.

What We Do

We publish a quarterly journal, *Academic Questions*, which examines the intellectual controversies and the institutional challenges of contemporary higher education.

We publish studies of current higher education policy and practice with the aim of drawing attention to weaknesses and stimulating improvements.

Our website presents educated opinion and commentary on higher education, and archives our research reports for public access.

NAS engages in public advocacy to pass legislation to advance the cause of higher education reform. We file friend-of-the-court briefs in legal cases defending freedom of speech and conscience and the civil rights of educators and students. We give testimony before congressional and legislative committees and engage public support for worthy reforms.

NAS holds national and regional meetings that focus on important issues and public policy debates in higher education today.

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About Freedom in Education

Mission

Promoting freedom in education by equipping parents & teachers. We endeavor to find, create, and promote solutions to the most pressing and destructive issues facing education in America today. Freedom in Education is committed to restoring parental rights, high-quality education, and civic virtue to our public schools by enhancing and improving content transparency, curriculum quality, and learning options and equipping parents to act.

What We Do

We empower and support "School Ambassadors" to advocate for educational solutions promoted and/or developed by our organization. These ambassadors, comprising parents, teachers, or community members aligned with our mission, serve as conduits between our solutions and classrooms. Their primary role involves nurturing and restoring relationships within the educational community as well as advocating for content-rich, non-politicized curricula at both local school and district levels.

Learn more by visiting https://freedomined.org/.

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New York State Education Department
From the New York State Education Department. *Elementary Science Core Curriculum Grades K-4*. 1996. Internet. Available from https://www.nysed.gov/sites/default/files/programs/curriculum-instruction/elecoresci.pdf; accessed 3 January 2024. Used with permission.

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Introduction

The Spirit of Benjamin Franklin

Science seeks to make sense of the natural world. Since its beginnings, America has prided itself on cultivating both scientific competence and a broad understanding of what science is, what is essential to know about science, and our responsibility as citizens to engage thoughtfully with science.

We may define science as informed and disciplined curiosity about the natural world. Scientific inquiry begins with questions about the natural world, but the questions themselves are the spawn of curiosity. Without curiosity, science instruction (and science itself) is a pointless exercise. Unfortunately, the focus of science education has been drifting away from these ideals. We need to restore informed and disciplined curiosity to American science education, along with the spirit and the rigor of America's first great scientist and inventor, Benjamin Franklin.

On a trip to England in 1757, Benjamin Franklin noticed that the wakes of most of the ships in the 96-ship fleet were ruffled by the wind while the wakes of two of the ships were smooth. With his curiosity stimulated, Franklin asked the captain, what was different about the two ships? The captain guessed that the cooks on the two ships must have emptied their greasy water into their wakes. Franklin decided to test the captain's hypothesis by performing an experiment.

As soon as he had the chance, Franklin dropped a teaspoonful of oil on a lake made rough by the wind. As the oil spread quickly upon the surface of the lake, he could see the spectral colors caused by the thin film of oil. The film became invisible as the oil continued to thin, but Franklin knew it was there because the water beneath it was stilled. From these experiments, Franklin surmised the molecular nature of oil and its interactions with water. From then on Franklin, ever the curious and thorough scientist, made it a habit to carry oil in the upper hollow joint of his bamboo cane and repeated the experiment whenever he had the chance.[1]

We need to restore the spirit of Benjamin Franklin to America's science classrooms. We therefore offer here *The Franklin Standards: Model K-12 State Science Standards* to America's states, citizens, schools, teachers, and parents.

1 "A Letter from Benjamin Franklin, to Dr. Brownrigg, Relative to the Use of Oil for Stilling the Waves," *U.S. Naval Institute Proceedings* 33/3/123 (1907), https://www.usni.org/magazines/proceedings/1907/july/letter-benjamin-franklin-dr-brownrigg-relative-use-oil-stilling.

The Need for New State Science Standards

State standards are the most important guideposts for K-12 science instruction in America's schools. State standards describe what should be taught in public schools, although they usually leave school districts and individual teachers significant leeway in how to teach. They also provide private schools, charter schools, and home schools with a set of guidelines to promote quality science education for all students.

The best state science standards from a generation ago, such as those of California, New York, and Massachusetts, did an excellent job at providing rigorous content, instructing students in scientific reason and method, and nurturing curiosity.[2] Since 2013, these excellent state science standards have been replaced with science standards modeled upon the Next Generation Science Standards (NGSS).[3] NGSS has been adopted by, or significantly influenced, the science standards of 44 states and the District of Columbia, while 48 state standards have been influenced either by NGSS or its predecessor *Framework for K-12 Science Education* (2010).[4]

Unfortunately, the NGSS has seriously degraded science education. Under the NGSS, content instruction has diminished, and science as a method of inquiry has been inappropriately replaced by rote acceptance of expert opinion and isolated facts. Students, shortchanged, are left unable to engage in the independent thought and critical thinking that science education should promote. Purely as pertains to its scientific rigor, the Fordham Institute gave NGSS a C grade.[5]

The NGSS also has driven the political and pedagogical radicalization of the science education profession. The NGSS has softened scientific and mathematical rigor, replacing them with "inquiry-based learning"—questions without answers—political activism, and the imperatives of "diversity" and "equity." Finally, NGSS has blurred the lines between activism and science. The National Association of Scholars (NAS) has detailed at length the deleterious consequences of NGSS' commitment to activism and equity.[6]

The NGSS were supposed to improve American students' scientific knowledge, but American science outcomes are still far below what they should be. In 2019, the United States spent $15,500 (in constant 2021 U.S. dollars) per full-time-equivalent (FTE) student on elementary and secondary education, an amount 38% higher than the Organization for Economic Cooperation and Development (OECD) average of $11,300, and fifth highest among the OECD member states.[7] In 2019-2020, the U.S.

2 *Science Content Standards for California Public Schools: Kindergarten Through Grade Twelve* (California State Board of Education, 1998, 2000, 2003), https://www.cde.ca.gov/be/st/ss/documents/sciencestnd.pdf; Science Learning Standards, New York State Education Department, https://www.nysed.gov/curriculum-instruction/science-learning-standards; *Massachusetts Science and Technology/Engineering Curriculum Framework* (Massachusetts Department of Education, 2006), https://www.doe.mass.edu/frameworks/archive.html. See also *National Science Education Standards* (Washington, D.C.: National Academy Press, 1996). https://nap.nationalacademies.org/catalog/4962/national-science-education-standards.

3 Next Generation Science Standards, http://www.nextgenscience.org; Tiffany Neill and Doug Paulson, "State Science Standards: An Overview and Analysis of Review, Revision, and Adoption Processes in States in the U.S.," https://www.nationalacademies.org/documents/embed/link/LF2255DA3DD1C41C0A42D3BEF0989ACAECE3053A6A9B/file/DB51C5F17C13BED8AB938B6BC188103DA22C20E8558F?noSaveAs=1.

4 State Adoption of Science Standards, Citizens for Objective Public Education, https://www.copeinc.org/docs/State-Adoptions.pdf.

5 Paul Gross, et al., "Final Evaluation of the Next Generation Science Standards," Thomas B. Fordham Institute, June 11, 2013, https://fordhaminstitute.org/national/research/final-evaluation-next-generation-science-standards.

6 Jennifer Helms, James Nations, and David Randall, *Climbing Down: How the Next Generation Science Standards Diminish Scientific Literacy* (National Association of Scholars, 2021), https://www.nas.org/reports/climbing-down.

7 Education Expenditures by Country, International Comparisons, National Center for Education Statistics, https://nces.ed.gov/programs/coe/indicator/cmd/education-expenditures-by-country.

spent $870 billion (in constant 2021–22 dollars) on K-12 education, a far larger absolute sum than any other country on the globe.[8] This total included sharply increasing expenditures dedicated to STEM education.[9]

Yet America did not benefit from any economies of scale. At best, sharply increasing American expenditures have maintained a flat level of students' scientific knowledge. In 2022, American students placed 18th out of 80 reporting countries in the Program for International Students Assessment (PISA) science results—and its absolute score remained around 500 from 2018 to 2022.[10] Among the 38 members of the OECD, the U.S. ranked 12th in science. America spends the 5th most on a per capita basis, and the most by far in absolute terms, yet gets the 12th best results.[11]

Another indication of the state of science and math education is the declining percentage of graduate students who received their K-12 education in the United States and have gone on to study science or engineering at our nation's leading research universities:

> At U.S. universities, international students account for 82% of the full-time graduate students in petroleum engineering, 74% in electrical engineering and 72% in computer and information sciences, 71% in industrial and manufacturing engineering, 70% in statistics, 67% in economics, 61% in civil engineering, 58% in mechanical engineering and agricultural economics, 56% in mathematics and applied mathematics, 54% in chemical engineering, 53% in metallurgical and materials engineering, 52% in materials sciences and pharmaceutical sciences.[12]

In key disciplines, such as electrical engineering, a large majority of the graduate students received their K-12 education outside of the United States. Too many American students who are interested in technology are unable to pursue degrees in engineering (and ultimately get high-paying jobs) because they are inadequately prepared.

American national interest also requires us to improve our K-12 science education. International measures show that China is rapidly catching up to the United States in research leadership in a wide variety of scientific fields, and already has achieved leadership in particular disciplines, especially in chemistry, materials science, and information science.[13] In 2018, only 9% of American students taking the PISA test were top performers in science (Levels 5 or 6), a far lower proportion than the 22.3% of Chinese students who were top performers.[14] America must educate larger numbers of excellent scientists, engineers, and technicians so that we can maintain our technological advantage over China.

American K-12 science education can and must do better.

8 Fast Facts: Expenditures, National Center for Education Statistics, https://nces.ed.gov/fastfacts/display.asp?id=66.

9 Andrea Peterson, "STEM Education Budget: FY22 Outcomes and FY23 Request," AIP, June 10, 2022, https://ww2.aip.org/fyi/2022/stem-education-fy22-outcomes-and-fy23-request.

10 Comparing countries' and economies' performance in science, PISA 2022: Insights and Interpretations, Hechinger Report, https://hechingerreport.org/wp-content/uploads/2023/12/Science-rankings-PISA-2022.pdf.

11 And see Sarah D. Sparks, "ACT: Only 1 in 5 High School Graduates in 2023 Fully Prepared for College," *Education Week*, October 11, 2023, https://www.edweek.org/teaching-learning/act-only-1-in-5-high-school-graduates-in-2023-fully-prepared-for-college/2023/10.

12 *International Students in Science and Engineering*, National Foundation for American Policy, August 2021, https://nfap.com/wp-content/uploads/2021/08/International-Students-in-Science-and-Engineering.NFAP-Policy-Brief.August-2021.pdf.

13 *2023 Research Fronts*, Clarivate, https://discover.clarivate.com/Research_Fronts_2023_EN.

14 Programme for International Student Assessment (PISA) Results from PISA 2018, OECD, https://www.oecd.org/pisa/publications/PISA2018_CN_USA.pdf; Students in B-S-J-Z (China) rank first in PISA 2018 survey, Ministry of Education, People's Republic of China, http://en.moe.gov.cn/news/press_releases/201912/t20191210_411536.html. China did not participate in the 2022 PISA, so more recent comparisons are not available. China's results are only for the four advanced provinces of Beijing, Shanghai, Jiangsu, and Zhejiang; China as a whole almost certainly does not have such an advantage over the United States, but it is reasonable to believe that China as a whole still has a higher proportion of top performers in science than the United States as a whole.

The Franklin Standards

In response, the National Association of Scholars (NAS) submits the *Franklin Standards: Model K-12 State Science Standards*. We offer these new standards to states, school districts, charter schools, private schools, home schools, and textbook publishers as a counter-model to the NGSS. The *Franklin Standards* provides science educators a better science standard, which states and schools will be able to adapt to fit their needs.

Fortunately, there is no need to reinvent the wheel. The best state science standards of the 1990s and early 2000s were quite good. The *Franklin Standards* builds upon the best aspects of previous state standards, particularly those of New York's 1996 standards and Massachusetts' 2006 standards,[15] which were deservedly highly rated by the Fordham Institute for their content.[16]

Our Expert Committee particularly focuses upon distinguishing between theory and evidence, which is essential for scientific reasoning. We emphasize that science is never settled, but is always subject to testing and revision, and should never be decided by authority or a consensus. Science education should help students acquire the scientific habit of subjecting theory to continued critical evaluation by learning early that even the most well-supported theories *are* theories, and not facts. We have revised much of the content of the best previous standards to make these distinctions and aims clear.

We also focus on *scientific methodology*, which includes what is normally taught as *the* scientific method (hypothesis, experiment, conclusion), but which accounts also for the broader range of methods scientists use for scientific exploration of nature. This goes against the grain of current science education, which asserts that *multiple ways of knowing* stand on an equal footing with *scientific knowledge*. We know that the scientific method is an ideal type of the ways scientists acquire knowledge, which may be applied differently in different disciplines, or to different scientific questions, or indeed to different bodies of evidence about the physical aspects of the natural world. Yet scientific methodology has been indispensable in the creation of the modern sciences—and likewise is indispensable for the present conduct and future practice of science. The *Franklin Standards* teaches students about the unique nature of scientific methodology as an essential component of the nature of science.

The *Franklin Standards* also focuses on scientific habits and character. Scientists accept that what they believe they know is ultimately provisional, and that they should accept correction of what they scientifically know when new evidence comes to light. This is the original "critical thinking"—very different from the radical catechizing derived from "critical theory" that now goes under the same name—which emphasizes the mutuality of criticism, and the willingness to subject oneself to criticism as much as the ability to criticize others. Scientific character encourages a spirit of humility and charity among scientists both in their dealings with one another and with the larger public.

The *Franklin Standards* removes large amounts of politicization and activism, and restores rigor simply by returning to the best state standards of the 1990s and early 2000s. A great many political

15 Science Learning Standards, New York State Education Department; *Massachusetts Science and Technology/Engineering Curriculum Framework*.

16 *The State of State Science Standards 2012* (Thomas B. Fordham Institute, 2012), https://fordhaminstitute.org/national/research/state-state-science-standards-2012.

battles about science standards concern material that was introduced by political activists in the NGSS and elsewhere. We provide standards for full and excellent science instruction in part by using materials produced before a hyper-politicized generation came to the fore in the education establishment and in part by updating our content to incorporate current scientific knowledge.

Science Education for All

The *Franklin Standards* offers improved science education for *all* students.

The *Franklin Standards* significantly broadens access to science education for teachers and students across the United States. The *Franklin Standards* moves away from the model provided by the NGSS standards, which are cumbersome and focus counterproductively on content-poor "inquiry-based learning." Instead, it offers lucid, content-rich guidance to teachers and properly prepares students for college, graduate school, scientific careers, and their civic duties as scientifically-literate citizens.

Some educators argue that schools should limit content instruction, even though a large body of education scholarship has shown their arguments are misguided.[17] Better-off students receive large amounts of content knowledge from their families and peers, but disadvantaged students must receive this content in school if they are to receive it at all. When disadvantaged students do receive this intensive content instruction, they learn eagerly and well.

Content standards that focus on "skills" and abbreviate content especially harm the education of disadvantaged students, and in so doing foster an unequal society. The *Franklin Standards* offers comprehensive content knowledge to ensure that America's schools fulfill the promise of equal educational opportunities for everyone.

The *Franklin Standards* provides teachers with robust content knowledge they can use to provide all American students a clear path to engage with, comprehend, and appreciate the wonders of the natural world. The *Franklin Standards*' flexibility gives teachers freedom to incorporate real-world examples and practical applications into their lessons that will be most appropriate and useful to their students. The clear organization of the *Franklin Standards* makes it easier for educators to read, understand, and teach science content in the classroom. Students also will benefit from a more structured learning path, which fosters a deeper understanding of scientific principles. These emphases ensure that teachers can provide appropriate science education for all Americans.

The *Franklin Standards* are intended to boost science knowledge of all students, and are not intended to be a substitute for early college classes taken in high school, such as the College Board's AP Biology, Chemistry, and Physics classes, the International Baccalaureate Organization's equivalents, and dual credit (taught in high school) and dual enrollment (taught in college) courses in advanced science. We encourage ambitious and qualified students to take early college courses, the better to stimulate their love of science and prepare them for college and career. But our model *Franklin Standards* provides self-sufficient science standards for all students, which early college classes may supplement but not replace.

17 Notable works such as Thomas Sowell's *Black Education: Myths and Tragedies* (1972), E. D. Hirsch's *The Schools We Need and Why We Don't Have Them* (1996), Annette Lareau's *Unequal Childhoods: Class, Race, and Family Life* (2003), and Abigail and Stephen Thernstrom's *No Excuses: Closing the Racial Gap in Learning* (2004) point out that disadvantaged students need intensive content instruction the most.

Structure of the Franklin Standards

Virtually all American science instruction focuses on the core disciplines of *Physical Sciences*, *Biology/Life Sciences*, and *Earth and Space Sciences*, and we think it is correct in doing so. *Life Sciences (Biology)* teaches about the nature of living organisms. *Earth and Space Sciences* teach about our planet and the universe. *Physics* and *Chemistry* teach about two essential scientific approaches to understanding the physical universe. We go beyond this core to include standards of *Scientific Inquiry*, *History of Science*, and *Technology and Engineering*.

Core Instruction: Physical Sciences, Life Sciences, Earth and Space Sciences

The *Franklin Standards* divides its core instruction into grade bands for Grades K-8, subdivided into *Physical Sciences*, *Life Sciences,* and *Earth and Space Sciences*. We also provide *Chemistry*, *Physics*, *Biology/Life Sciences*, and *Earth and Space Sciences* standards for Grades 9-12.

Expanded Instruction: Scientific Inquiry, History of Science, and Technology and Engineering

To facilitate students' ability to distinguish between theory and practice and learn about the nature of scientific reasoning, we offer *Scientific Inquiry*. *History of Science* teaches students how we came to know what we know about the natural world. *Technology and Engineering* ensures that students will have basic knowledge of these subjects and preparation for careers in engineering and related fields.

Scientific Inquiry

The *Scientific Inquiry* standards include three different sections.

The first section, which applies to all K-12 science education, includes the four subsections of **Scientific Knowledge**, **Scientific Reasoning**, **Limitations of Scientific Knowledge**, and **Scientific Habits and Character**. **Scientific Knowledge** includes definitions of *fact*, *hypothesis*, *experiment*, *theory*, *scientific law*, *proof*, *causation*, *correlation*, *deductive reasoning*, *inductive reasoning*, and *abductive reasoning*, as well as the prescription that **Scientific Knowledge** requires the continuing assessment of the quality of scientific evidence, including its replicability and its transparency. **Scientific Reasoning** reintroduces sustained attention to a broader concept of *scientific methodology*, which includes what is normally taught as *the* scientific method (hypothesis, experiment, conclusion), but which accounts also for the broader methods scientists use for scientific exploration of nature.[18] **Limitations of Scientific Knowledge** covers the limited scope of scientific reasoning, the all-too-human fallibility of scientific reasoners, and, ultimately, the theoretical limits to the scientific knowledge we can acquire about the universe. **Scientific Habits and Character** emphasizes what John Dewey called "intellectual

18 North Carolina recently reintroduced instruction in the scientific method into its state science standards. North Carolina Standard Course of Study, K-12 Science, July 2023, https://wwwcache.wral.com/asset/news/education/2023/07/06/20942864/Updated_3rd_DRAFT_of_Proposed_K-12_Science_Standards_-_July__2023_3635163hvsgnrblescr15gd3kacqoz-DMID1-5zhlkelha.pdf.

hospitality," the humility and civility that allows for permanent dissent and civil discussion among scientists, who wisely realize that they may be mistaken as they search for truth.

The second section consists of the sequences within each individual K-12 standard, which improve upon the "Skills" and "Practices" sections of state standards. Current instruction in scientific "skills" and "practices" obscures, abbreviates, or even eliminates instruction in the unique nature of scientific reasoning and scientific methodology. We have designed these sequences, and drafted their content, to devote them to the analytical and procedural knowledge that is necessary to learn and understand science.

The third section provides further skills and practices that apply to all four high school science standards. Rather than repeat this section in each of those four standards, we have placed this section at the beginning of the high school science standards.

History of Science

Science is enriched by knowledge of the history of scientific discovery. Science instruction can be enriched by this history too, by helping both teachers and students to learn how we came to know what we know about the natural world. Learning the history of scientific discovery will help teachers plan the sequence of science instruction and the choice of laboratory experiments and field exercises. The history of science also helps students learn about how scientific debate works, and the character of civil scientific dissent. Students may be inspired to choose careers in science by learning how individual men and women made scientific discoveries.

The history of science has come to be a neglected component of science instruction,[19] and in our lifetimes it has disappeared from most science courses. We provide the *History of Science* standards so that states and school districts may choose to integrate them with science instruction, to augment but not to replace core science instruction. The *History of Science* standards provide a cumulative outline of the history of science.

Technology and Engineering

The history of America is very much the history of tinkerers and engineers, from Benjamin Franklin's lightning rod and his Franklin stove to the innovations of hydraulic fracturing and the automotive design of Tesla. The Constitution enshrines America's love of science and its application in Article One, Section 8, which dedicates our republic to promoting "the progress of science and useful arts."

The balance of American science education between theoretical and applied science has changed over time. Many states have broadened science instruction to include dedicated coverage of the practical application of science (engineering) and an understanding of the current state of applied science (technology). More formally, *engineering* concerns the theory and design of engines, machines, processes, and structures, while *technology* concerns the implementation, application, operation, maintenance, and repair of engines, machines, processes, and structures.

Technology and Engineering is a valuable complement to science education, but it should not be taught at the expense of basic science instruction, which is essential for engineers as much as for

19 *National Science Education Standards*.

professional scientists and citizens. We therefore provided the *Technology and Engineering* standards so that states and school districts may choose to integrate them with science instruction, to augment but not to replace core science instruction. We have integrated and modified the *2006 Massachusetts Standards*' coverage of engineering, in the form of Grades K-8 instruction by grade band, as well as a distinct high school course in engineering.

The Franklin Standards in the Classroom

Classroom Time Limits

We know that teachers only have limited time for each topic. The *Franklin Standards* is framed to respect those limits. We strongly encourage science classes to incorporate as much of *History of Science* and *Technology and Engineering* as possible within the available time. The core material of the *Franklin Standards* remains *Physical Sciences*, *Earth and Space Sciences*, and *Biology/Life Sciences*. *Scientific Inquiry* should be integrated into all subject matter instruction.

Some schools divide their pre-AP high-school instruction into multiple courses; e.g., Biology 1 and Biology 2 before AP Biology. We have provided enough material in our standards for schools with this fuller science coverage. We expect that schools with less coverage will select appropriate units from the *Standards*. Generally, we expect and encourage states and school districts to expand and compress the *Standards* to suit local needs.

Some schools also unite the different disciplines into high-school courses that cover related portions of Biology, Chemistry, Physics, and/or Earth and Space Sciences. We expect that these schools will incorporate material from our *Standards* to suit their course structure.

We indicate some material with asterisks, in the high school standards. These standards indicate more advanced material, which teachers may include where appropriate and when time permits.

Many items in the standards are accompanied by parenthetical lists. The items in parentheses are *examples* of what can be taught. Teachers are not expected to teach every item we list in parentheses, nor are they limited to those items.

Fostering Curiosity

Students are naturally curious and standards should support teachers' work to cultivate the disciplined and informed curiosity that is the hallmark of scientific inquiry and its distinctive way of understanding and improving the world. The *Franklin Standards* provide foundational content knowledge of the language and concepts of science–but they are not meant to *limit* science instruction to what is in these standards. Concretely, we urge states, school districts, charter schools, private schools, home schools, teachers, and parents to reserve substantial portions of science instruction time to cultivate students' curiosity.

Pedagogy

The *Franklin Standards* provides *teaching standards* consisting of a content-rich, bullet-point list of required knowledge, with equal standards for every student, so as to restore a culture of high expectations to K-12 science education. We provide rich standards to ensure that science teachers do not compromise on content, and that the desire to improve *how* to teach science never compromises *what* should be taught. We focus on lucid statements of scientific knowledge that every citizen should know.

Because the *Franklin Standards* does not mandate or forbid specific instructional methods, teachers are free to choose appropriate content-focused pedagogies that will promote student learning. The *Standards* also allows any state education department to provide pedagogy guides for teachers.

We drafted many of our items to prompt laboratory and field observations and experiments. Lab periods are marvelous for instilling both love of science and a practical knowledge of how it works. They are particularly useful for conveying science instruction to students with a wide range of aptitudes for science. Field trips can particularly benefit students who have too few opportunities to observe nature, in the wild or in special locations such as science museums, zoos, botanical gardens, and laboratories. We hope that state pedagogy guides will include many model field and laboratory observations and experiments, as well as suggestions for field trips.

The content-rich *Franklin Standards* also makes clear what *teachers* should be expected to know, and what state education departments can expect of teachers. The *Franklin Standards* outlines what teachers should learn, whether in college, graduate school, or professional development. It helps teachers to arrange content so that it builds coherently over several years, and to know what is appropriate for each grade level. It facilitates state and school district assessments of scientific knowledge and licensure standards and provides clear and copious material for such assessments. It makes possible an entire apparatus of improved approaches to teacher training, licensure, textbooks and assessment, all geared to producing students who graduate from high school with deep and broad scientific knowledge, informed curiosity about the natural world, and a love of learning.

Complementary Mathematics Instruction

Mathematics helps students think abstractly and learn those scientific concepts that are best stated in mathematical form. You cannot use scientific concepts in many professional and vocational careers without knowing how to use and apply mathematics. State mathematics standards should complement state science standards by outlining the rigorous mathematics education needed to prepare students for college, career, and citizenship. We do not provide that outline here, but we emphasize that Algebra I should be taught in the eighth grade to provide enough time for substantial further mathematics education in high school. High school mathematics also should include Algebra II and Geometry, which are essential for high school science. The study of exponents and logarithms is especially important.

Conclusion

The *Franklin Standards* offers excellent science education standards to help teachers provide the content-rich science education students need to be free, productive, and wise citizens. Americans need and deserve the best science education in the world. The NGSS and its derivatives will doom our children to scientific mediocrity or worse. The *Franklin Standards*, modified to fit local situations in each state and school district, provides a distinct alternative. With the *Franklin Standards*, Americans can reclaim their scientific and technological heritage, as a nation second to none of scientists, engineers, and informed citizens–much like Benjamin Franklin himself. All Americans should be able to explore every realm of scientific inquiry and to apply the knowledge they have learned to ensure the liberty, the prosperity, and the security of the United States of America.

The Model K–

12 Standards

Kindergarten–High School Scientific Inquiry Standards

1. Scientific inquiry relies on understanding the nature of scientific knowledge. Students will know:
   1.1 The purpose of natural science is to develop rational, objective, and realistic descriptions and explanations of the natural world.
   1.2 The underlying presumptions of the pursuit of scientific knowledge, including the existence of objective reality, the capacity of human senses and reason to achieve knowledge of objective reality, the existence of the natural world as a distinct domain of inquiry, and that the natural world is governed by uniform laws and processes which may be described, explained, and used to predict what will be observed under future specific conditions.
   1.3 That scientific discovery begins with an exciting and/or surprising observation, followed by a need to explain the observation as well as a need to test the explanation through further observations or experiments. This cycle is repeated no matter where the evidence leads, until the mystery is solved and a discovery is made.
   1.4 That scientific inquiry includes logical reasoning, trial and error, observation, and controlled experiments.
   1.5 The differences among scientific facts, theories, hypotheses, experiments, and laws.
   1.6 That a scientific fact is an observation that has been repeatedly confirmed by multiple independent researchers.
   1.7 That a scientific theory is a generally accepted yet conditional and repeatedly tested explanation of many observations or experimental results.
   1.8 That a scientific theory is falsifiable; i.e., that it can be shown to be false through experimental observation.
   1.9 A scientific hypothesis is a measurable and testable statement that is derived from theory that explains or predicts a given phenomenon of the natural world.

1.10 That scientific experiments and observations are methods of testing a hypothesis or distinguishing between alternative hypotheses.
1.11 A scientific law is a simple, useful, and universal quantitative statement about a phenomenon under nearly all conditions.
1.12 How to define and distinguish between *cause and effect* (one thing causes another) and *correlation* (two things occur together).
1.13 How to define and distinguish between deductive reasoning (from the general to the specific) and inductive reasoning (from the specific to the general).
1.14 How to define abductive reasoning as intuition from limited data rather than from a theory.
1.15 That the validity of a theory depends upon continued verification by repeated tests of hypotheses.
1.16 That the acceptance of a theory by consensus or authority does not establish its validity.
1.17 That scientific reasoning includes a continuing and skeptical assessment of the underlying assumptions and the quality of scientific evidence and analysis, including its reproducibility and its transparency.

2. Scientific inquiry relies on using scientific reasoning, which includes the scientific method. Students will know:
2.1 Science begins with curious wonder about the natural world and the desire to pose a question that will produce greater understanding.
2.2 Scientists use scientific methodology to discover knowledge that is universally true and which can be confirmed by anyone who replicates a scientific inquiry.
2.3 Scientific methodology is used to investigate the natural and objective world, and must include scientific reasoning (including deductive, inductive, and abductive reasoning) disciplined by objectivity and rationality, and investigation to obtain evidence by observation or experiment.
2.4 The formal *scientific method* provides a common framework for introducing the traditional experimental design and hypothesis-testing process.
2.5 The stages of the scientific method include identifying a question to be answered, gathering information about a problem, generating one or more testable hypotheses, formulating a method that tests the hypotheses by gathering evidence by means of experiments and other forms of disciplined observations, and stating and defending a conclusion based upon reason and evidence.
2.6 New conclusions may lead scientists to revise old hypotheses and test new ones.

3. Scientific inquiry relies on knowing the limitations of scientific knowledge. Students will know:
   - 3.1 That scientific knowledge remains conditional even when it is widely accepted, and can never be said to be proven as it remains subject to falsification by new evidence.
   - 3.2 How one should skeptically assess popular reports of scientific research by judging whether the evidence and analysis presented supports the claim.
   - 3.3 That scientific research often includes rigorously applied statistical methodology.
   - 3.4 That statistics provides probabilistic evidence, including the possibility that a conclusion is wrong.
   - 3.5 That statistical correlations can show relations, but not causations.
   - 3.6 That scientific research must include transparently documented methods and data to allow replication.
   - 3.7 That all mathematical models are simplified simulations of the real world, whose assumptions at first may be chosen arbitrarily and should only be accepted conditionally, and whose predictions until tested are inherently uncertain.
   - 3.8 How various kinds of motivations and perspectives can alter popular and professional presentations of scientific research.
   - 3.9 That scientists may be fallible, that sometimes they are motivated to become self-interested observers, that they may overestimate the extent of their expertise, and that they may sometimes lack full data about the object of scientific inquiry.
   - 3.10 Scientific methodology is limited to the observable natural and objective world, and should be used cautiously when assessing subjective human attitudes, beliefs, and opinions.
   - 3.11 That scientific reasoning can inform but not replace moral reasoning, aesthetic reasoning, prudential reasoning, and teleological reasoning, and that it cannot be used to make final judgments about values, beauty, action, or purpose.

4. Scientific inquiry relies on scientific habits and character. Students will know that scientific habits and character include:
   - 4.1 A desire to observe the natural world with a disciplined curiosity leavened with healthy skepticism.
   - 4.2 A mind prepared by broad knowledge and understanding of science to take advantage of chance observations.
   - 4.3 A disposition to consider in a thoughtful way the scientific problems and subjects that come within the range of one's experiences in order to formulate questions that are testable against evidence.
   - 4.4 Recognition that there are many obstacles in the search for truth, including the concealment of one's own biases and ignorance and the blind acceptance of authority, tradition, and consensus.

4.5 A disposition to examine any scientific belief or supposed knowledge in the light of existing evidence and to re-examine scientific beliefs or supposed knowledge in the light of new evidence.
4.6 A commitment to follow the evidence wherever it might lead.
4.7 Scientific integrity, humility, and civility, including
    4.7.1 honest recording, open sharing, and transparent reporting of the thinking, data, observations, and processes that lead to scientific knowledge;
    4.7.2 commitment to free and fearless scientific exchange of ideas in disinterested pursuit of truth;
    4.7.3 willingness to be shown to be mistaken;
    4.7.4 understanding that censorship is contrary to the ethics and practice of science;
    4.7.5 recognition that scientific validity is independent of the personal attributes of the scientist;
    4.7.6 understanding that not all questions can be addressed by scientific inquiry;
    4.7.7 tolerance of persisting intellectual disagreement, and;
    4.7.8 understanding that science is never settled.
4.8 Ethical scientific practice, including commitment to ensure the well-being of researchers, teachers, and students, including laboratory safety, and commitment to informed consent to ensure the physical well-being of human subjects of experiments.
4.9 Seeking to balance the greatest benefits and least harm to human welfare, the necessity sometimes to consider trade-offs in pursuing these sometimes conflicting goals, and the necessity to explain and justify them.

Kindergarten

Physical Sciences

1. Matter exists in many forms.
    1.1 *Matter* takes up space and has *weight*. Two objects cannot occupy the same place at the same time.
    1.2 *Matter* has *properties* that can be observed, described, and measured.
    1.3 Some *properties* are observed and described by the senses (color, shape, odor, sound, taste, hardness/softness, type of material); others are observed, described, and measured with tools (length, width, volume, shape, size, weight).
    1.4 *Matter* can exist in different *forms*: *solid* (ice), *liquid* (water), or a *gas* (steam).
    1.5 *Matter* that can be seen or touched is called an *object*.

Life Sciences

2. Life on Earth comes in many forms, including animals, plants, fungi and bacteria, which may differ from one another, and have things in common.
    2.1 All living things take in nutrients, grow, reproduce, eliminate waste, and die.
    2.2 Bacteria (microorganisms) cannot be seen without microscopes, but are an important aspect of life on Earth.
    2.3 Animals need air, water, and to eat food produced by other living things.
    2.4 Plants create their own food from carbon dioxide, water, and sunlight.
    2.5 Fungi feed themselves by decomposing animals and plants.

Earth and Space Sciences

3. The Earth is made of water, rocks, soil, and living organisms, and gets its light and heat from the Sun.
    - 3.1 The Sun supplies the Earth with light and heat, both of which are necessary for life.
    - 3.2 Water, rocks, soil, and living organisms are found on the earth's surface.
    - 3.3 Organisms modify the habitats in which they live (roots, lichens, worms, corals, beaver dams).

4. The night sky is different from the day sky.
    - 4.1 Objects of the night sky include the Moon, planets, stars, constellations, and satellites.
    - 4.2 Objects of the day sky include the Sun and the Moon.
    - 4.3 Objects in the day and night skies move in predictable ways.

Technology and Engineering

5. Natural and artificial materials have specific characteristics that determine how they can be used. As a basis for understanding this concept, students know:
    - 5.1 How to identify and describe characteristics of natural materials (wood, cotton, fur, wool, clay, water).
    - 5.2 How to identify and describe characteristics of artificial materials (plastic, modeling clay, foam board).
    - 5.3 Material characteristics such as strength, hardness, and flexibility.
    - 5.4 How to build a basic structure with teacher-provided materials.

History of Science

6. Curious people have observed the world around them to try to understand it and have used art, music, and literature to describe what they saw. Students will:
    - 6.1 Listen to and summarize poems and stories that illustrate contributions to the history of science and love of scientific study of the world, such as Richard Armour's *Pachycephalosaurus*, Steven Vincent Benet's *Benjamin Franklin*, Robert Frost's *Canis Major*, and Christina Rosetti's *Who Has Seen the Wind?*
    - 6.2 Look at paintings that illustrate nature (cave paintings and rock art, Audubon, Bierstadt, Merian, Monet, da Vinci).
    - 6.3 Sing songs about nature (The Skeleton Dance).
    - 6.4 Know how these poems, stories, paintings, and songs illustrate contributions to the history of science and love of scientific study of the world.

Scientific Inquiry

7. Students should:
   - 7.1 Be curious about and explore the natural world around them.
   - 7.2 Observe and describe something that they find interesting in words and pictures and share why it is interesting.
   - 7.3 Describe objects in or aspects of the natural world in terms that others can understand and use to discover things about those objects on their own.
   - 7.4 Listen to the observations of others and answer their questions.
   - 7.5 Continue to follow curiosity and wonder by asking questions about other objects, organisms, and events in the environment.

Grade One

Physical Sciences

1. Matter has observable properties.
    1.1 An object's material (wood, ice, plastic, cotton, metal) determines some of its properties (sinking/floating, color, texture, magnetism).
    1.2 Objects can be sorted or classified according to their properties (large and small, red and blue, heavy and light, rough and smooth, transparent and opaque).
    1.3 Some properties of an object are dependent on the condition of its surroundings, including temperature (melted vs. solid butter), humidity (soggy vs. crispy potato chips), and sunshine (color in a picture faded from too much light).
    1.4 Natural materials come from plants (cotton), animals (leather), and earth materials (clay, gravel). Artificial materials are man-made (plastic, manufactured glass).

2. Describe physical changes, including changes in states of matter.
    2.1 Matter exists in three *states* (forms): solid (ice), liquid (water), and gas (steam). *Solids* have a definite shape and volume, *liquids* do not have a definite shape but have a definite volume, and *gases* do not hold their shape or volume.
    2.2 Temperature can affect the state of matter.

Life Sciences

3. All living things use various adaptations to sustain their lives.
    3.1 The environment influences the form and function of organisms (light, gravity, moisture, and temperature). Different environments may require specific adaptations for survival and thriving (thick fur in cold weather, long legs, gills in water, lungs in air).

3.2 Plants living in different environments have different adaptations (different leaf shape in sun or shade, tall trees versus low shrubs, succulents in deserts).
3.3 Plants respond to changes in their environment (leaf fall in autumn, plant growth and budding in spring, seed set at different times of year).
3.4 Animals respond to changes in their environment (perspiration in hot environments, shivering in cold environments, salivating in anticipation of food, fat storage and hibernation in winter).
3.5 Many animals, including humans, move from place to place to find favorable environments (migration) or food (hunting, farming).
3.6 Animals may create favorable environments for themselves or their offspring (nests, animal colonies, burrows).
3.7 The health, growth, and development of organisms are affected by environmental conditions such as the availability of food, air, water, space, shelter, heat, and sunlight.

Earth and Space Sciences

4. Weather can be observed and its components can be described and measured.
   4.1 *Weather* is the condition of the outside air at a particular moment.
   4.2 Weather changes from day to day and over the seasons.
   4.3 The description of weather includes general sky conditions such as cloudy, sunny, and partly cloudy.
   4.4 Weather can be described and measured by temperature (thermometer), wind speed and direction (anemometer and wind vane), form and amount of precipitation (rain gauge).

5. Maps and globes are used to represent the Earth and the sky.
   5.1 Maps and globes are used to represent Earth's surface features, Earth's weather, and features of the night sky and Moon.

Technology and Engineering

6. Natural and artificial materials have specific characteristics that determine how they will be used. As a basis for understanding this concept, students know:
   6.1 How to identify and explain some possible uses for natural materials (wood, cotton, fur, wool).
   6.2 How to identify and explain some possible uses for artificial materials (plastic, memory foam, foam board).

6.3 How to measure length (ruler), volume (measuring cup), weight (scale), and time (clock).
6.4 How to identify and describe the safe and proper use of tools and materials (glue, scissors, tape, ruler, paper, toothpicks, straws, spools) to construct simple structures.

History of Science

7. Students learn about exciting individuals who have shaped our scientific understanding of the world, through stories, literature and art. Students will:
    7.1 Read or listen to true stories about famous scientists who have made extraordinary contributions to the history of science.

    Such as: Luis Alvarez, Mary Anning, Archimedes, George Washington Carver, Albert Einstein, Michael Faraday, Benjamin Franklin, Galileo Galilei, Jane Goodall, Ibn al-Haytham, and Isaac Newton.

    7.2 Describe the qualities or traits (curious, careful, sense of wonder) of these famous scientists that led them to make scientific discoveries.

Scientific Inquiry

8. Students should:
    8.1 Describe and classify material objects by their properties (size, hardness, color, living).
    8.2 Name and use simple equipment and tools (rulers, thermometers, hand lenses, balances) to describe material objects.
    8.3 Ask a question about how material objects might be affected if some condition changes, make a prediction, and find out what happens.
    8.4 Discuss with others both observations and whether the prediction was correct.

Grade Two

Physical Sciences

1. Objects can be measured.
   - 1.1 Properties can be observed and measured with tools such as hand lenses, rulers, thermometers, balances, magnets, and measuring cups.
   - 1.2 Measurements can be made with standard English units (ounces, pounds, inches, feet, degrees Fahrenheit [°F]).

2. Matter interacts through forces that result in changes in motion.
   - 2.1 The *position* of an object can be described by locating it relative to (above, below, left, right, in front of, behind) another object or the observer.
   - 2.2 The *position* and *direction* of motion of an object can be changed by pushing or pulling. Pushing or pulling is called *force*.
   - 2.3 An object's *speed* is how much its distance from something changes over time.
   - 2.4 An object's *acceleration* is how much its speed changes over time.
   - 2.5 Tools and simple machines (pulleys, levers, and inclined planes) can apply forces on objects and affect their *speed* and *direction*.
   - 2.6 Objects tossed into water can produce water waves.
   - 2.7 Sound waves can be produced by objects in motion (drums, stringed instruments).
   - 2.8 The force of gravity pulls objects toward the center of Earth.
   - 2.9 Magnetism is a force that may attract or repel certain materials.

Life Sciences

3. All living things have life cycles, which include the stages of birth or hatching, growth, maturity, reproduction, and death. Life cycles of different creatures may vary in specialized ways.

3.1 The length of an organism's life cycle is called its *life span*. Life spans of different organisms vary.
3.2 Life cycles of different types of animals may add new stages or remove certain stages (larvae, pupation and metamorphosis, asexual reproduction, incubation).
3.3 Life cycles of plants include germination, vegetative growth, sexual reproduction through flowers, seed set, fruits.
3.4 Growth involves both increase in size of the organism, and maturation to the reproductive stage of the life cycle.
3.5 Growth, maturation, and reproduction all require food and energy.
3.6 Some traits of living things have been inherited (e.g., color of flowers and number of limbs of animals).
3.7 An individual organism's form and function may change in response to changes in the individual's environment (adaptation).
3.8 Some adaptations acquired during an individual's lifetime may be inherited in the next generation.

Earth and Space Sciences

4. Different types of climate exist on Earth.
   4.1 Climate varies over different spatial scales (local vs. regional) and time scales (seasonal vs. multi-decennial).
   4.2 Different climate zones are distributed by latitude (polar, temperate, subtropical, equatorial), and elevation above sea level (mountains).
   4.3 Different climate zones contain distinct physical features (glaciers, deserts, rain forests, coral reefs).

5. Earth is composed of rocks and minerals, has fossils, and is affected by weathering and erosion.
   5.1 A rock is an aggregate of one or more minerals. Approximately ten rock-forming minerals make up most of the rocks of Earth (feldspar, quartz, mica, clay minerals).
   5.2 Minerals have distinctive physical properties (hardness, color, luster, cleavage, and streak).
   5.3 Fossils are the impressions or remains of prehistoric organisms (animal bones, dinosaur tracks, petrified wood, insects in amber). Fossils can be used to study past climates and environments.
   5.4 The dynamic processes that wear away Earth's surface include weathering and erosion.
   5.5 The process of weathering breaks down rocks to form sediment. Soil consists of sediment, organic material, water, and air.

Technology and Engineering

6. Engineering design requires creative thinking to solve practical problems. As a basis for understanding this concept, students know:
    - 6.1 How to describe how human beings use parts of the body as tools (teeth for cutting, hands for grasping and catching, or feet for running and kicking).
    - 6.2 How to compare the ways in which animals and humans use parts of the body as tools.
    - 6.3 How to identify tools and simple machines used for a specific purpose (ramp or inclined plane, wheel, axle, screw, wedge, pulley, lever and fulcrum, bucket).
    - 6.4 How to use tools for measurement, and how hands and feet can be used for measurement.
    - 6.5 The advantages and disadvantages of using parts of the body versus artificial tools.

History of Science

7. Students learn about exciting individuals who have made disciplined observations and used experiments to advance scientific knowledge and transform our way of thinking scientifically about the world. Students will:
    - 7.1 Read or listen to true stories about famous scientists that illustrate the use of scientific reason and experimental design.

      Such as: Eratosthenes' calculation of the circumference of the Earth, Galileo Galilei and his telescope, Antonie van Leeuwenhoek and his microscope, Maria Sybilla Merian and her illustrations, Benjamin Franklin and his kite, Gregor Mendel and his garden, and Marie Curie and the electrometer.

    - 7.2 Describe the qualities or traits (curious, careful, sense of wonder) of these famous scientists that led them to make scientific discoveries.
    - 7.3 Describe how scientists have developed instruments to observe what cannot be observed directly with the unaided senses.

Scientific Inquiry

8. Students should:
    - 8.1 Know the basic elements of a scientific inquiry, including making observations, asking a testable question (hypothesis), testing the hypothesis with an experiment or observations, and drawing a conclusion from the evidence.

8.2 Describe the observations and steps of the scientific inquiry.
8.3 Record observations and data with pictures, numbers, or written statements.
8.4 Discuss observations and conclusions with others.

Grade Three

Physical Sciences

1. Describe a variety of forms of energy (heat, chemical, light) and the changes that occur in objects when they interact with those forms of energy.
    - 1.1 The Sun's rays (*radiant energy*) warm the air, water, and land. *Radiant energy* on Earth also comes from hot objects such as lava, electric heaters, and hot coals.
    - 1.2 Energy is stored in many ways: in food, gasoline, charcoal, batteries, water in a water tower, coiled springs, hot cocoa in a thermos.
    - 1.3 Energy may be transferred over distances (electricity, light, waves, objects in motion).
    - 1.4 Energy and matter interact: ice melts and water evaporates from the Sun's heat; a bulb produces light from an electrical current; a musical instrument produces sound; black objects absorb light, shiny objects reflect light.
    - 1.5 Energy cannot be created or destroyed, but can be changed from one form to another (*law of conservation of energy*).
    - 1.6 When energy is changed from one form to another, some energy is always converted to heat in the process. Some systems transform energy with less loss of heat than others.
    - 1.7 Heat can be released in many ways; for example, by burning, rubbing (friction), or combining one substance with another.
    - 1.8 Energy allows work to be done (energy in gasoline or propane to run a car, energy in muscles to build a fence).
    - 1.9 Humans convert energy from one form to another with different devices (electrical energy to produce sound energy from a doorbell, chemical energy in a battery to do work in a calculator, solar cells to store light energy in a battery, energy in elevated water to produce hydroelectric power).
    - 1.10 Humans and animals convert energy in food to heat and motion.

Life Sciences:

2. Students are introduced to the history of life on Earth.
   - 2.1 Life at present is different from life in the past.
   - 2.2 Evolution is change over time and species come into existence and go extinct at different times.
   - 2.3 Some kinds of organisms that once lived on Earth have completely disappeared (gone extinct) and new kinds have appeared.
   - 2.4 "Zoic" refers to animals and describes the outlines of the history of life on Earth, including the names of the major epochs (Archaean, Proterozoic (earliest animals), Paleozoic (early animals), Mesozoic (middle animals), Cenozoic (new animals)).
   - 2.5 The Paleozoic, Mesozoic, and Cenozoic epochs each had characteristic flora and fauna.
   - 2.6 A scientifically reliable outline of the history of life on Earth has been reconstructed based on the fossil record.

Earth and Space Sciences

3. The planets and moons of the Solar System and their motions.
   - 3.1 The names of the planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and the dwarf planet Pluto. A belt of asteroids orbits between Mars and Jupiter.
   - 3.2 Planets, moons, and asteroids are made of rocks, soil, ices (water, methane), liquids, and gases.
   - 3.3 *Rotation* is the spinning of a planet or moon on its axis (day and night) and *revolution* is the orbit around the Sun or a planet.
   - 3.4 *Relative motion* is the perceived movement of an object from the perspective of another object (movement of Earth around Sun and movement of Moon around Earth)
   - 3.5 Earth spins around once every 24 hours (rotation), resulting in day and night.
   - 3.6 Earth takes one Earth year to move in a path around the Sun (revolution), resulting in seasons.
   - 3.7 The length of daylight and darkness varies with the seasons.
   - 3.8 The Moon viewed from the Earth exhibits *phases* as it moves in a path around Earth to complete a single cycle (full, new, waxing, waning, crescent, gibbous).
   - 3.9 Many planets have moons orbiting them.
   - 3.10 *Eclipses* occur when one object in the solar system (moon or planet) casts a shadow on another object (lunar eclipses, solar eclipses).
   - 3.11 The ocean tides are associated with the motion of the Moon around the Earth.

3.12 The Sun and other stars appear to move in a recognizable temporal pattern both daily and seasonally.
3.13 When viewed from Earth's surface, certain stars form spatial patterns, called *constellations*.
3.14 Exploration of space has included human landings on the Moon (Apollo Program).

Technology and Engineering

4. Materials, tools, and machines extend our ability to solve problems and invent new devices. As a basis for understanding this concept, students know:
   4.1 How to identify suitable materials (metal, paper) to accomplish a design task based on specific properties (strength, hardness, and flexibility).
   4.2 How to identify and explain the use of suitable materials and tools (hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) to construct a given prototype safely.
   4.3 How to compare and contrast simple and complex machines (a sundial vs. a watch, a hand-held can opener vs. an electric model with multiple gears).

History of Science

5. Students learn about epic stories of scientific discoveries and pivotal individual scientists who changed how we understand the world. Students will:
   5.1 Learn about the lives and discoveries of famous scientists who have contributed to our understanding about light.

   Such as: Euclid (visual rays), Al-Haytham (light rays), Isaac Newton (light particles), Thomas Young (light waves).

   5.2 Learn about the lives and discoveries of famous scientists who have contributed to our understanding of fossils.

   Such as: Mary Anning (ichthyosaurs), Edward Cope and Othniel Marsh (North American dinosaurs), Roy Chapman Andrews (dinosaur eggs).

   5.3 Learn about the lives and discoveries of famous scientists who have contributed to our understanding of the solar system.

Such as: Ptolemy (ancient view of the solar system), Nicolaus Copernicus (heliocentrism), Galileo Galilei (telescope), Isaac Newton (gravitation), Edwin Hubble (universe beyond the galaxy).

Scientific Inquiry

6. Students should:
   - 6.1 Know that the validity of a scientific conclusion depends upon repeatability of the evidence.
   - 6.2 Know that objective evidence differs from subjective opinion.
   - 6.3 Select and use appropriate tools and technology (calculators, computers, balances, scales, rulers, graduated cylinders) in order to make more accurate observations.
   - 6.4 Know that objective evidence is subject to variation, so that no two observations are likely to be identical.
   - 6.5 Know how to produce bar graphs to present quantitative data and interpret the graph to others.

Grade Four

Physical Sciences

1. Describe how electricity and magnetism produce forces that operate across distances.
   - 1.1 There are two *electric charges*, *positive* and *negative*.
   - 1.2 Two objects that have the same *electric charge* repel each other (*positive* repels *positive*, or *negative* repels *negative*); objects with the opposite *electric charge* attract each other (*positive* attracts *negative*). Attraction and repulsion are *forces* produced by the electric charges (static electricity).
   - 1.3 Electricity (*electric current)* consists of *negative* charges moving through a wire.
   - 1.4 *Electric current* moving through a wire can convert electrical energy into other forms of energy: mechanical energy from a motor, light from a bulb, and heat from anything that resists the flow of the *electric current*.
   - 1.5 A simple electric circuit can use a battery to generate an electric current that runs a light bulb or a motor.
   - 1.6 When *electric current* moves through a wire, it produces a *magnetic field* that surrounds the wire.
   - 1.7 *Magnets* also produce a *magnetic field*.
   - 1.8 *Magnets* attract certain metals like iron.
   - 1.9 *Magnets* have *north and south poles.*
   - 1.10 As with electric charges, two *magnets* with the same *poles* close together repel each other (*north poles* repel *north poles*, *south poles* repel *south poles*); two *magnets* with different *poles* close together attract each other (*north poles* attract *south poles*). Attraction and repulsion are *forces* produced by the magnetic fields.
   - 1.11 In a compass, a small magnet aligns with the Earth's magnetic field to point toward the magnetic north pole.
   - 1.12 A compass can be constructed from a magnetized needle.
   - 1.13 When *electric current* flows through a wrapped wire (coil), a *magnetic field* is created.

1.14 A simple *electromagnet* consists of wire wrapped around a piece of iron or a similar metal. A simple *electromagnet* can be constructed from wire, a nail, and a battery.

1.15 *Electromagnets* in different devices convert electrical energy into other forms of energy (sound from electromagnets in earphones and doorbells, motion from electromagnets in motors).

Life Sciences

2. All living things exist in ecosystems, which include humans and other species that form communities, and the environment in which they live.

   2.1 Ecosystems consist of *food webs,* which represent the flows of matter and energy between the environment and the organisms inhabiting it.

   2.2 Energy enters food webs through green plants, which manufacture food by capturing energy in sunlight to make sugars from carbon dioxide and water. Green plants are known as *autotrophs* (self-feeding), *photoautotrophs,* or *primary producers*.

   2.3 Green plants also provide the food supply for animals that eat them. These animals are *primary consumers*.

   2.4 Some animals (predators) eat other animals (prey) and are known as *secondary consumers*.

   2.5 All animals are known as *heterotrophs* (*other-feeding*).

   2.6 Many fungi and microorganisms feed off the remains of once-living things and are known as *saprotrophs* (rot-feeding), or *decomposers*.

   2.7 A food web continually cycles matter between interacting autotrophs, heterotrophs, and saprotrophs.

   2.8 In an ecosystem, each organism's form, function, and behavior are influenced by the environment (kinds and numbers of other organisms present, the availability of food and other resources, the environment's physical characteristics).

   2.9 When the environment changes, some organisms are better able to thrive, and other organisms are less able to do so.

   2.10 In response to local environmental changes, some organisms migrate to other locations where the environmental conditions are more favorable.

Earth and Space Sciences

3. Rocks can be classified and their formation can be described by the concept of the rock cycle.

   3.1 The three classes of rocks are sedimentary, metamorphic, and igneous, which are formed in different ways. Most rocks show characteristics that give clues to the conditions of their formation.

3.2 Sedimentary rocks are formed by deposition of sediments over long periods of time (sandstone, limestone). Metamorphic rocks are formed when one type of rock is subjected to high heat and pressure (quartzite, marble). Igneous rocks are formed when molten minerals cool (granite, basalt, obsidian).
3.3 The rock cycle derives from the motion of continental plates over time (plate tectonics).
3.4 The rock cycle shows how types of rock or rock material may be transformed from one type of rock to another.
3.5 State and national geographic maps can be used to find the location and characteristics of major physical features and rock types.
3.6 The same processes that form rocks and minerals on Earth also form rocks and minerals on other rocky planets and moons (volcanoes, erosion, sedimentation).

4. Many of the phenomena that we observe on Earth involve interactions among components of air, water, and land.
   4.1 Water is recycled by natural processes on Earth, including *evaporation* (changing of water (liquid) into water vapor (gas)), *condensation* (changing of water vapor (gas) into water (liquid)), *precipitation* (rain, sleet, snow, hail), *runoff* (water flowing on Earth's surface), and *infiltration* (water that moves downward into the ground).
   4.2 The actions of flowing air and water break earth materials down into smaller particles (erosion).
   4.3 The actions of flowing air and water transport earth materials from one place to another (deposition).
   4.4 Pieces of earth material also may be moved by gravity, volcanic activity, and the motion of glaciers.
   4.5 Soil is composed of decaying living (organic) material mixed with nonliving earth material.
   4.6 Extreme natural events (floods, droughts, fires, earthquakes, volcanic eruptions, hurricanes, tornadoes, severe storms) may have positive or negative effects on living things.

Technology and Engineering

5. Engineering design requires intuition, creative thinking, and methods to solve practical problems and invent new solutions and devices. As a basis for understanding this concept, students know:
   5.1 How to identify a problem of necessity or convenience (shelter, storage, transport).
   5.2 How to describe different ways in which a problem can be represented (sketches, diagrams, graphic organizers, and lists).

5.3 How to identify relevant design features (size, shape, weight, energy efficiency) for building a prototype solution to a given problem.
5.4 That *biomimicry* is the design of artificial systems inspired by the function of natural systems (airplane wings and bird wings, Velcro and cockleburs, house beams and animal bones).

History of Science

6. Students learn about epic stories of scientific discoveries and pivotal individual scientists who changed how we understand the world. Students will:
   6.1 Learn about the lives and discoveries of famous scientists who have contributed to our understanding about electricity.

   Such as: William Gilbert (electricity), Benjamin Franklin (lightning), Alessandro Volta (battery), Luigi Galvani (bioelectricity), Michael Faraday (electric motor, Christmas Lectures for children).

   6.2 Learn about the lives and discoveries of famous scientists who have contributed to our understanding of biogeography.

   Such as: Carl Linnaeus (classification), Alexander von Humboldt (plant geography, ecology), Alfred Russel Wallace (biological evidence for continental drift).

   6.3 Learn about the lives and discoveries of famous scientists who have contributed to our understanding of plants and agriculture.

   Such as: John Bartram (botanical garden), Luther Burbank (fruits), George Washington Carver (peanuts), Norman Borlaug (Green Revolution).

Scientific Inquiry

7. Students should:
   7.1 Distinguish between evidence and interpretation.
   7.2 Discuss how scientists might interpret the same evidence in different ways.
   7.3 Keep accurate records while conducting simple investigations or experiments.
   7.4 Conduct a scientific inquiry with procedures determined by the teacher, which includes multiple trials to test a prediction.
   7.5 Compare the result of an investigation or experiment with the prediction.
   7.6 Communicate and *critically* discuss how the scientific inquiry was performed and how to interpret the results.

Grade Five

Physical Sciences

1. Describe atoms, elements, compounds, and chemical reactions.
    - 1.1 All matter is made up of atoms. Atoms are far too small to see with a light microscope.
    - 1.2 There are 92 naturally-occurring types of atoms as well as some that are made artificially. Each of these different types of atoms is called an *element*.
    - 1.3 The atoms of each of the *elements* have different properties.
    - 1.4 The *elements* are arranged by their properties on the *periodic table*. For example, metals, nonmetals, and noble gases are found in separate areas.
    - 1.5 The *periodic table* was used to predict the existence of unknown elements.
    - 1.6 Atoms of the same or different *elements* combine to form *compounds*.
    - 1.7 A *molecule* is an independent group of atoms (elements) in which their type and number are unique and bound by attractive forces known as *chemical bonds* in a stable configuration. Examples of *molecules* include water (H_2O), nitrogen (N_2), oxygen (O_2), and table sugar (sucrose; $C_{12}H_{22}O_{11}$).
    - 1.8 Atoms and molecules are in constant motion that increases with temperature.
    - 1.9 Interactions among atoms and/or molecules result in *chemical reactions*.
    - 1.10 In a chemical reaction, *reactants* are converted into *products*. The atoms are not changed in a chemical reaction but they are arranged differently in the products that form.
    - 1.11 Elements combine in a multitude of ways to produce compounds that account for all living and nonliving substances. Few elements are found in their pure form.
    - 1.12 It took until the early twentieth century (1905) for physicists to come up with a theory and experiments to provide convincing evidence for atomic theory.
    - 1.13 Single atoms can be seen with a scanning tunneling microscope.

2. Distinguish between chemical and physical changes.
    2.1 During a physical change a substance keeps its chemical composition. Examples of physical changes include freezing, melting, condensation, boiling, evaporation, tearing, and crushing. A *phase change* is a physical change from one form (state) to another (solid, liquid, gas).
    2.2 Pure compounds are distinguished from mixtures.
    2.3 Mixtures are physical combinations of materials and generally can be separated by physical means.
    2.4 During a chemical change, substances react in characteristic ways to form new substances with different physical and chemical properties. Examples of chemical changes include burning of wood, cooking of an egg, rusting of iron, and souring of milk.
    2.5 The Law of Conservation of Mass states that during chemical reactions (non-nuclear reactions) matter cannot be created or destroyed. In chemical reactions, the total mass of the reactants equals the total mass of the products.
    2.6 In chemical reactions, energy is transferred into or out of a system. Light, electricity, or mechanical motion may be involved in such transfers in addition to heat.

Life Sciences

3. Animals' whole body organ systems control breathing, circulation of the blood, ingestion and digestion, metabolism and elimination of wastes, locomotion, and sensory and nervous systems.
    3.1 The cell is the fundamental unit of life. Cells are usually microscopic in size. All cells convert food into readily available energy. All cells grow and divide, producing more cells.
    3.2 Tissues, organs, and organ systems help to provide all cells with nutrients, oxygen, and waste removal.
    3.3 The digestive system processes food for physical (grinding, churning) and chemical breakdown of ingested food, absorption of nutrients into the blood, and elimination of solid wastes.
    3.4 The mouth and stomach break down food into nutrients,
    3.5 The small intestine digests food into nutrients for absorption across the intestinal wall into the blood.
    3.6 The large intestine (colon) ferments hard-to-digest food, shelters micro-organisms for production of vitamins, and begins to recover water from the residue.
    3.7 The rectum molds remaining solid waste into feces for elimination from the body.
    3.8 The excretory system functions in the disposal of dissolved waste molecules and the elimination of liquid and gaseous wastes.

3.9 During respiration, cells use oxygen to release the energy stored in food. The respiratory system supplies oxygen and removes carbon dioxide (gas exchange).

3.10 The circulatory system consists of the heart, arteries to transport blood from the heart, veins to return blood to the heart, and capillaries to connect arteries to veins. It supports the respiratory system by transporting gases between the cells and the lungs.

3.11 The heart pumps the blood through its own chambers and throughout the rest of the body.

3.12 Organisms regulate their body temperature through *endothermic mechanisms* (internal generation of heat) or *ectothermic mechanisms* (obtaining heat from the environment).

3.13 Locomotion, necessary to escape danger, obtain food and shelter, and reproduce, is accomplished by the interaction of the skeletal and muscular systems, and coordinated by the nervous system.

3.14 The nervous and endocrine systems interact to control and coordinate the body's responses to changes in the environment, and to regulate growth, development, and reproduction.

3.15 The nerves, brain, and spinal cord gather and process sensory information to make decisions for the whole organism.

3.16 Hormones are chemicals produced by the endocrine system, which regulate many body functions.

3.17 The male and female reproductive systems are responsible for producing sex cells necessary for the production of offspring.

3.18 The skin is the largest organ of the human body. It protects the body from the environment and provides thermal regulation (sweating, blood flow).

4. Describe the major nutrients, sources of energy, vitamins, and minerals that maintain health and promote growth.

4.1 Food provides molecules that serve as fuel and building material for all organisms. All living things, including plants, must release energy from their food, using it to carry on their life processes.

4.2 Foods consist of carbohydrates, proteins, and fats.

4.3 Water, vitamins, and minerals found in foods also are vital for metabolism and ensuring survival of the organism.

4.4 Metabolism is the sum of all chemical reactions in an organism. Metabolism can be influenced by hormones, exercise, diet, and aging.

4.5 Energy in foods is measured in Calories. Calories with an uppercase C (kilocalories) are used for convenience and they are one thousand times greater than calories with a lowercase c. The number of Calories a person requires daily varies from person to person based on metabolism, physical activity, and environmental temperature.

4.6 All organisms require a minimum daily intake of each type of nutrient based on factors including species, size, age, sex, and activity. Too much, too little, or irregular intake of any of the nutrients might result in weight gain, weight loss, or disease.

4.7 Information about food's caloric and nutrient content may be seen in food labels provided on foods purchased from stores.

Earth and Space Sciences

5. The Earth and celestial phenomena can be described by principles of relative motion and perspective.

   5.1 Earth's Sun is an average-sized star. The Sun is more than 300,000 times the Earth's mass, more than one hundred times its diameter, and more than a million times greater in volume.

   5.2 Other stars are like the Sun but are so far away that they look like points of light. Distances between stars are vast compared to distances within our solar system.

   5.3 The Sun and the planets that revolve around it are the major bodies in the solar system. Other members include comets, moons, and asteroids.

   5.4 Gravity is the force that keeps planets in orbit around the Sun and moons in orbit around their planets. The orbits of the planets, moons, and asteroids are elliptical, including Earth's.

   5.5 Most objects in the solar system have a regular and predictable motion, which sets length of day and year for all planets, and such phenomena as eclipses, seasons, tides, meteor showers, and comets.

   5.6 The latitude/longitude coordinate system and our system of time are based on celestial observations.

   5.7 Stars shine by their own light, while planets and their moons are seen by reflected stellar light.

   5.8 Moons orbit their planets, while planets orbit the Sun. Our Moon orbits Earth, while Earth orbits the Sun. The Moon's phases as observed from Earth are the result of seeing different portions of the lighted area of the Moon's surface. The Moon's phases repeat in a cyclic pattern over a period of about one month.

   5.9 The observed motions of the Sun, Moon, planets, and stars across the sky can be explained by assuming the Earth is stationary even though it rotates around its axis and revolves around the Sun (relative motions).

   5.10 Earth's rotation causes the Sun and Moon to appear to rise along the eastern horizon and to set along the western horizon.

5.11 Earth's rotation sets the length of one day at approximately 24 hours, and Earth's revolution around the Sun defines the length of the year as 365 ¼ days. Calendars must have a *leap day* added every four years to make up for the quarter day of each year.

5.12 The tilt of Earth's axis of rotation (relative to its orbital axis) and the revolution of Earth around the Sun cause seasons on Earth. The length of daylight varies depending on latitude and season.

5.13 The shapes of Earth, the other planets, and stars are nearly spherical, although they bulge out at the equator.

5.14 It took a long time to assemble the evidence that provided conclusive support for the belief that the Earth and the planets orbit the Sun (heliocentric theory) rather than that the Sun and the planets orbit the Earth (geocentric theory).

5.15 The debate between heliocentrism and geocentrism illustrates the general importance of frame of reference and perspective for evaluating astronomical observations (absolute versus apparent brightness, absolute versus relative motion).

Technology and Engineering

6. We can use materials, tools, and machines to solve problems, invent, and construct. As a basis for understanding this concept, students know:

6.1 How to identify and explain the use of appropriate measuring tools, hand tools, and power tools used to hold, lift, carry, fasten, and separate (tape measure, screwdriver, crowbar, jack).

6.2 How to describe the use of tools (rubber mallet vs. steel hammer) based on the physical characteristics of the materials (strength, hardness, flexibility, dimensions, mass, density, and composition).

6.3 How to identify appropriate materials to solve a design task (wood, paper, plastic, clay, aggregates, ceramics, metals, adhesives) based on specific properties and characteristics (strength, hardness, and flexibility).

6.4 How to identify and explain the safe and proper use of measuring tools, hand tools, and machines (band saw, drill press, sander, hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) needed to construct an engineering design prototype.

History of Science

7. Students learn about the development of scientific methodologies. Students will:

7.1 Learn about the ancient Greek philosophical tradition (Thales, Plato, and Aristotle).

7.2 Learn about medieval Scholastic reasoning (Roger Bacon), medieval Islamic experimentalism and mathematical reasoning (Ibn al-Haytham), and Renaissance observational and experimental practices (Tycho Brahe, Galileo Galilei).
7.3 Learn about early modern scientific methodologies, including the scientific method (inductive and experimental methods of Francis Bacon, deductive method of René Descartes, experimental method of Robert Boyle, Isaac Newton's rules of reasoning).

Scientific Inquiry

8. Students should:
    8.1 Design and conduct an experiment specifying variables to be changed, controlled, and measured.
    8.2 Formulate a testable hypothesis.
    8.3 Select appropriate tools and technology (calculators, computers, thermometers, meter sticks, balances, graduated cylinders, microscopes), know how to use them safely, and make quantitative observations.
    8.4 Present and explain data and findings using multiple representations, including tables, graphs, mathematical and physical models, and demonstrations.
    8.5 Draw conclusions based on data or evidence presented in tables or graphs, and make inferences based on patterns or trends in the data.
    8.6 Communicate procedures and results using appropriate science and technology terminology.
    8.7 Offer explanations of procedures, identify sources of error, and critique and revise the experiment.

Grade Six

Physical Sciences

1. Identify different sources and forms of energy.
    1.1 The primary inputs of naturally occurring energy to the surface of the Earth are radiant energy from the Sun, thermal energy from nuclear decay in the core of the Earth, and energy left over from the formation of the Earth.
    1.2 Different forms of energy include heat (fireplace), light (flashlight), sound (music from a speaker), electrical (voltage at an outlet), mechanical (moving bicycle, springs, drawn string in a bow), water (dams), wind (wind turbines), nuclear (fission in a power plant reactor), and chemical (reactions, voltage from a battery).
    1.3 These different forms of energy consist of either *kinetic energy*, which is the energy of motion (projectile), or *potential energy*, which consists of stored energy. Stored energy can be electrical, gravitational, spring, nuclear, or chemical.
    1.4 Energy is stored when something moves from a position of lower *potential energy* to a position of higher *potential energy* (a spring being compressed, water pumped up into a water tower). When something moves from a position of higher *potential energy* to one of lower *potential energy*, energy is released. This released energy takes the form of *kinetic energy* (a spring uncoiling and flying away, water flowing down from a water tower).
    1.5 Most activities in everyday life involve one form of energy being transformed into another. For example, the chemical energy in food, gasoline, or an electric battery (*potential energy*) is transformed into the energy of motion (*kinetic energy*) in human running or an automobile engine moving a car. Energy, in the form of heat, is almost always one of the products of energy transformation.

2. Observe and describe heating and cooling events.
    2.1 Heat moves from warmer objects to cooler ones, until both objects reach the same temperature.

2.2 Heat flows from a warm region to a cooler region through matter by *conduction* and through space by *radiation*. In a liquid or gas, currents transfer heat by *convection*.

2.3 The *rate* of heat flow depends on the temperature *difference*, the manner of heat flow (*conduction, convection, radiation*), and the *thermal conductivity* of the materials.

2.4 Material with high *thermal conductivity* readily conducts heat (metals, water). Materials with low *thermal conductivity* (cork, fiberglass, air) conduct heat poorly and are used for thermal insulation.

2.5 The rate of heat flow by *convection* will vary depending upon the degree of motion (wind speed).

2.6 The rate of heat flow by *radiation* will vary depending upon the distance between two objects (distance from a radiator).

2.7 Actual temperature is different from perceived temperature (wind chill, "feels like").

2.8 During a phase change, heat energy is absorbed or released without any change in temperature. Heat energy is absorbed when a solid changes to a liquid and when a liquid changes to a gas. Heat energy is released when a gas changes to a liquid and when a liquid changes to a solid.

2.9 Most substances expand when heated and contract when cooled. Water is an exception, expanding and becoming less dense when changing from liquid water to ice.

Life Sciences

3. Energy and matter flow through ecosystems via interacting food webs.

3.1 Energy flows through ecosystems, beginning usually from sunlight, to green plants, through consumers of green plants (primary consumers), through consumers of primary consumers (predators), and through consumers of the remains of plants and animals (decomposers).

3.2 The energy flow process may be visualized with food webs. Food webs identify feeding relationships among producers, consumers, and decomposers in an ecosystem.

3.3 *Energy* also can enter ecosystems independent of sunlight (chemoautotrophy), as in hydrothermal vents and hot springs.

3.4 Organisms need useful (chemical) energy to support life. The majority of useful energy is transformed into unusable heat at each link in a food web. Because energy is lost at each link of the food web, there are more green plants than prey and more prey than predators.

3.5 All energy is eventually lost from the ecosystem as heat to the environment (entropy).

3.6 Matter is transferred within food webs and between food webs and the physical environment. Water, nitrogen, carbon, and oxygen are examples of substances cycled between the living and nonliving environment.

4. Green plants use energy in sunlight to make food that supports ecosystems and food webs.
   - 4.1 Photosynthesis is carried on by green plants and other organisms containing chlorophyll (photoautotrophs). In this process, the Sun's energy is converted into and stored as chemical energy in the form of sugars.
   - 4.2 Photosynthesis is the major source of atmospheric oxygen. Carbon dioxide is removed from the atmosphere and oxygen is released during photosynthesis.
   - 4.3 Green plants are the primary producers of food, which is used directly or indirectly by consumers.
   - 4.4 The quantity of nutrients produced by autotrophs is known as *primary productivity,* which supports the function of the entire ecosystem.

5. Life is ordered and complex and can only be maintained by a constant input of energy (dynamic disequilibrium). Homeostasis is the set of physiological processes that use energy to sustain the organism's dynamic disequilibrium.
   - 5.1 All living organisms have a particular (specified) form characteristic of the species, which requires maintaining a specified pattern of complex organization (low entropy).
   - 5.2 Because the organism naturally loses energy, the organism's specified pattern of complex organization is unstable (increasing entropy).
   - 5.3 Maintaining the organism's complexity requires a constant input of energy (dynamic disequilibrium).
   - 5.4 When energy input ceases, the organism can no longer maintain the complex disequilibrium necessary for life, and it degrades to the equilibrium state of death (maximal entropy).
   - 5.5 *Homeostasis* is the set of physiological processes that sustain the organism's specified pattern of complex organization through time. These processes regulate the organism's internal environment (body temperature, salt and water balance, digestion).
   - 5.6 Homeostasis depends upon the organism's ability to sense and respond adaptively to its external environment.
   - 5.7 Living organisms can work to create homeostasis in their environments, although external conditions often disrupt their efforts. Environmental homeostasis may include interactions of multiple species and organisms, which may be competitive, harmful to one another, or mutually beneficial (symbiosis).

Earth and Space Sciences

6. Describe the composition and motions of the atmosphere.
   - 6.1 The atmosphere is a mixture of gases, including nitrogen and oxygen with small amounts of argon, water vapor, carbon dioxide, and other trace gases, confined by gravity to a thin shell around the planet.

6.2 The atmosphere is stratified into layers, each having distinct properties (troposphere, stratosphere). Nearly all weather occurs in the lowest layer of the atmosphere (the troposphere).
6.3 The atmosphere exerts an *atmospheric pressure*, which decreases with altitude above sea level.
6.4 The atmosphere's *barometric pressure* (atmospheric pressure reduced to sea level) varies over time and region, influencing weather.
6.5 Distinctive cloud types (cumulus, cirrus, cumulonimbus, and stratus) form in different atmospheric conditions.
6.6 Not every cloud leads to precipitation, but the energy stored by evaporation is released when the cloud forms by condensation.

7. Describe the composition and motions of the lithosphere.
    7.1 The rock at Earth's surface, which is divided into sedimentary, metamorphic, and igneous rocks, forms a nearly continuous shell around Earth called the lithosphere.
    7.2 The lithosphere is fractured into large plates which move with respect to one another (tectonic motion).
    7.3 Plate motions are driven by convective fluid motions in the *mantle*.
    7.4 Rock cycles through the lithosphere by subduction, plate spreading, and vulcanism.
    7.5 Minerals are identified on the basis of physical and chemical properties such as streak, hardness, and reaction to acid.
    7.6 Fossils are usually found in sedimentary rocks.
    7.7 Erosion (the breakdown of earth materials) is produced by the effects of wind, water, ice fracturing, and glacial ice.
    7.8 Gravity is the driving force behind deposition (transport of earth materials), in which sediment settles out of wind, water, and glacial ice.
    7.9 World geological maps can be used to find the location and characteristics of major physical features and rock types.

8. Describe the composition and motions of the hydrosphere.
    8.1 The majority of the lithosphere is covered by a thin layer of water called the hydrosphere.
    8.2 The water cycle describes how water circulates through the atmosphere, lithosphere, and hydrosphere.
    8.3 *Fresh water* is water lacking a significant salt content.
    8.4 Rivers carry salts weathered from rocks to the oceans, which is the source of their salt content.
    8.5 Rivers are parts of larger drainage systems, which gather water from rainfall or snow melt over a large surface area (*watersheds*), and in which flows may be temporary (*ephemeral*).

8.6 Drainage from watersheds can produce floods depending upon the shape and organization of the drainage channels (flash floods, flood plains).
8.7 Almost three quarters of the Earth's surface is covered with water, most of the land is in the northern hemisphere, and the southern hemisphere is mostly water.
8.8 Advancing and retreating glaciers shape Earth's surface by scouring rocks and transporting materials.
8.9 The size of Earth's ice caps and glaciers has varied greatly over time, causing substantial changes in sea levels and locations of coastlines.
8.10 Different types of deltas are created based on their shape, the size of the deposited material, and the process that shapes them (tidal, wave action, river dominated). Many deltas have alluvial fans, shaped like the Greek letter *delta* (Δ).
8.11 Most of Earth's fresh water is stored in ice caps and glaciers. Fresh water also may be stored in groundwater, bogs, marshes, swamps, fens, and ephemeral riverbeds, which can affect drainage patterns and flows.

Technology and Engineering

9. Engineering design is an iterative process that involves modeling and optimizing to develop technological solutions to problems within given constraints. As a basis for understanding this concept, students know:
   9.1 How to identify and explain the steps of the engineering design process (identify the need or problem, research the problem, develop possible solutions, select the best possible solution(s), construct a prototype, test and evaluate, communicate the solution(s), and redesign).
   9.2 How to demonstrate ways to represent solutions to a design problem (sketches, orthographic projections, multiview drawings, computer-aided design).
   9.3 How to describe, explain, answer questions about, and justify the purpose of a given prototype.
   9.4 How to identify appropriate materials, tools, and machines needed to construct a prototype of a given engineering design.
   9.5 How to explain technical (design features such as size, shape, weight, function, power consumption), cost, and schedule limitations that would affect the construction of a given prototype.
   9.6 How to identify appropriate safety and environmental considerations.
   9.7 How to identify the five elements of a universal systems model: goal, inputs, processes, outputs, and feedback.
   9.8 How engineers use theory and practice to design structures, machines, and processes.

10. Construction technology involves building structures to contain, shelter, manufacture, transport, communicate, and provide recreation. As a basis for understanding this concept, students know:
    10.1 How to describe and explain the functions of structural parts (foundation, flooring, decking, wall, roofing systems).
    10.2 How to identify and describe major types of bridges (arch, beam, cantilever, suspension) and their appropriate uses (site, span, resources, load-bearing).
    10.3 How to explain how the forces of tension, compression, torsion, bending, and shear affect the performance of bridges.
    10.4 How to describe and explain the effects of loads and structural shapes on bridges.
    10.5 How to construct a simple structure that they have designed.

History of Science

11. Students learn about the contributions of Enlightenment scientists to advance scientific knowledge and scientific reasoning, especially in the earth and space sciences. Students will:
    11.1 Learn about the role of the Enlightenment in the development of scientific thought (rationalism, skepticism, philosophical societies, dissemination of knowledge, American Enlightenment).
    11.2 Learn about the role of Enlightenment scientists in the development of earth and space sciences, such as Georges Cuvier (geology), Benjamin Franklin (climatology), Caroline and William Herschel (astronomy), James Hutton (geology), Thomas Jefferson (climatology), and Charles Lyell (geology).

Scientific Inquiry

12. Students should:
    12.1 Integrate complex instrumentation and tools (microscopes, telescopes, cameras, balances, cell phones, calipers, computers) into collecting, analyzing, and presenting data from a scientific inquiry.
    12.2 Record and display data using spreadsheets, scatterplots, line graphs, and diagrams.
    12.3 Recognize patterns in data (straight lines vs. curved lines).
    12.4 Based on the data, create a reasonable explanation for the results.
    12.5 Communicate findings to others using graphs, charts, maps, models, oral reports, and written reports.
    12.6 Listen to feedback from the teacher and students and use it, where appropriate, to update conclusions.

Grade Seven

Physical Sciences

1. Observe and describe properties of materials, such as thermal conductivity, solubility, density, and buoyancy.
    1.1 Substances have characteristic *properties*. Some of these properties include color, odor, hardness, thermal conductivity, solubility, phase at room temperature, and density.
    1.2 Temperature and pressure can affect the properties of a material.
    1.3 One of the properties of a substance that is affected by temperature is its solubility. *Solubility* is the amount (mass or weight) of a substance (the *solute*) that will dissolve in a fixed amount of *solvent* (salt in water).
    1.4 The rate at which a substance (*solute*) dissolves depends on its solubility, the size of its particles, the rate of stirring, and the amount of *solute* already dissolved.
    1.5 The motion of molecules and the attractive forces between them explain the phases (states) of matter as well as changes from one phase to another. The motion of molecules increases and the attractive force decreases as the substance changes from solid to liquid to gas.
    1.6 Gases assume the shape and volume of a closed container.
    1.7 A *liquid* has a definite volume but takes the shape of a container.
    1.8 A *solid* has a definite shape and volume.
    1.9 Characteristic properties (density, polarity, charge, chemical reactivity, hardness) can be used to identify different materials and separate a mixture of substances into its components.
    1.10 Insoluble substances can be separated from soluble substances by such processes as filtration or settling. Evaporation can be used to separate either a soluble or insoluble substance from its solvent. Iron can be removed from a mixture by means of a magnet.

1.11 *Density* is the amount of mass that occupies a given volume. If two objects have equal volume, but one has more mass, the one with more mass is denser.

1.12 *Buoyancy* is determined by the relative densities of the object and the fluid in which it is immersed. An object whose density is greater than that of the surrounding fluid will sink (negative buoyancy), and an object whose density is less than that of the surrounding fluid will float (positive buoyancy).

2. Describe the source and transmission of sound, light, and electricity.

2.1 Vibrations are wave-like disturbances that spread away from the source. Sound and light waves are examples. Vibrational waves move at different speeds in different materials. Sound waves travel much more slowly than light waves.

2.2 Sound is a pressure wave that cannot travel in a vacuum. Light is an electromagnetic wave that can travel both in a vacuum and in transparent materials.

2.3 *Sonar* (SOund Navigation And Ranging, submarines, whales, bats, ultrasound) uses sound waves to detect objects.

2.4 Visible light is an example of *electromagnetic energy*. Different forms of *electromagnetic energy* have different *wavelengths*. These include, in order of decreasing wavelength, radio waves, microwaves, infrared light, visible light, ultraviolet light, X-rays, and gamma rays.

2.5 *Radar* (RAdio Detection And Ranging, air traffic control towers, weather radar) uses invisible radio waves or microwaves to detect objects.

2.6 Electrical energy can be generated from a variety of sources (lightning, batteries, generators, solar panels) and can be transformed into other forms of energy.

2.7 Electric current travels in a closed circuit.

2.8 Electrical circuits provide a means of transforming electrical energy into other forms of energy (sound in radios, pictures on display screens).

3. Observe and describe the properties of light and its interactions with matter.

3.1 Material surfaces may *absorb* light (black or colored material), *reflect* light (shiny material), or *transmit* it, that is, allow it to pass through (transparent material).

3.2 When light is transmitted through transparent materials, it will change direction as it passes from one medium to another (air to water). This is called *refraction*.

3.3 To see an object, light emitted by or reflected from it must enter the eye.

3.4 Light from the sun radiates out in every direction from the sun.

3.5 A flashlight produces a beam of light that diverges as it travels from the source. A laser pointer produces a narrow beam of light that diverges very little even at long distances.

3.6 White light can be separated into its various colors using refraction (prism) or interference (diffraction grating, thin film).

3.7 Light invisible to humans (ultraviolet and infrared) exists on both sides of the visible light spectrum. Different animals can perceive wavelengths of light that are invisible to humans (bees see in the ultraviolet, pit vipers sense in the infrared).
3.8 Light is used for vision, mimicry, attraction, and warning coloration.
3.9 Coloration in living systems makes use of reflection, refraction, diffraction, interference, polarization, and bioluminescence.
3.10 The study of light and its interaction with mirrors, lenses, and other objects is called *optics*.

Life Sciences

4. All living things are composed of cells. Multicellular organisms are differentiated cells organized into larger systems.
    4.1 All cells are bounded by a *plasma membrane*, and in some instances (plants, fungi) by a surrounding *cell wall*.
    4.2 The internal organization of bacterial cells (*prokaryotes*) differs in fundamental ways from the internal organization of cells of animals, plants, fungi, and protists (*eukaryotes*).
    4.3 Eukaryotic cells contain a nucleus, and specialized *organelles* for metabolism (mitochondria), storage and secretion (endoplasmic reticulum), and structural support and locomotion (cytoskeleton).
    4.4 Plant cells contain a specialized organelle, the chloroplast, for photosynthesis.
    4.5 Multicellular organisms (animals, plants, fungi) are organized communities of eukaryotic cells.
    4.6 Plants and animals are composed of specialized cells organized into tissues and organs dedicated for specific functions.
    4.7 Levels of organization for structure and function of a multicellular organism include cells, tissues, organs, and organ systems.
    4.8 Organ systems of animals include blood circulation, breathing, digestion, regulating water and salt content, and sensory and nervous functions.
    4.9 All animals have similar organ systems, although these may differ between different types of animals (vertebrates vs. insects).
    4.10 Plants have specialized structures for obtaining water and soil nutrients (roots), gas exchange (stomata), making food (chloroplasts), and transporting these through the plant (xylem and phloem).
    4.11 In multicellular organisms, cell division is responsible for growth, maintenance, and repair.
    4.12 Cancers are a result of unregulated cell division.

5. Genes are passed from generation to generation through asexual and sexual reproduction.
    5.1 Genes can specify *heritable traits* that are passed from parent to offspring (eye color, hair color).
    5.2 *Genes* are heritable nucleotide sequences of deoxyribonucleic acid (DNA).
    5.3 *Chromosomes* are long molecules of DNA within which genes reside.
    5.4 One gene may correspond to a single heritable trait (sickle cell anemia, cystic fibrosis).
    5.5 Many heritable traits may be specified by more than a single gene (eye color, coat color).
    5.6 The sum of all an organism's genes is known as the *genome*.
    5.7 The expression of all an organism's active genes is known as the *phenotype (phenome)*.
    5.8 Prokaryotic genomes consist of single copies of hundreds to thousands of genes, usually on a ring-shaped chromosome.
    5.9 Eukaryotic genomes consist of duplicate copies (diploid) of tens of thousands of genes, usually on multiple thread-like chromosomes.
    5.10 Each cell of a multicellular organism contains a copy of all the genes needed to produce the entire organism.
    5.11 In asexual reproduction, all an offspring's genes come from a single parent, so that asexually produced offspring are genetically identical to the parent (clones).
    5.12 In sexual reproduction, typically half of the genes come from each parent (paternal and maternal haploid *alleles*). Sexually produced offspring are not identical to either parent.

6. Describe simple mechanisms related to the inheritance of some physical traits in offspring.
    6.1 In all organisms, genetic traits are passed on from generation to generation.
    6.2 In diploid organisms, either the maternal or paternal alleles may be expressed as dominant or recessive.
    6.3 The probability of a trait being expressed can be predicted using models of genetic inheritance, and by tools such as pedigree charts and Punnett squares.
    6.4 The environment may influence heritable traits (epigenetics, Hunger Winter studies).

7. Describe theories of biological evolution.
    7.1 There is a distinction between evolution as a historical phenomenon and the explanations for how evolution works.
    7.2 There is a hierarchy in the Linnaean classification (taxonomy) of *taxa* (domain, kingdom, phylum, class, order, family, genus, species).
    7.3 There is a difference between *microevolution* (origin of adaptations and species) and *macroevolution* (origin of higher taxa).
    7.4 Independent lines of evidence from the fossil record and comparative anatomy describe the phenomenon of evolution.

7.5 There are major transition points in the history of life (origin of life, origin of eukaryotes, origins of animals and higher plants, origins of intelligence (consciousness), origins of conscience (theories of T. H. Huxley, A. R. Wallace, S. Wilberforce)).
7.6 Evolution can occur through modifications over generations along familial lines of descent.
7.7 The basic outline of Darwinian theory includes adaptation, variation, heritability, natural selection, and small modifications of lineages over generations along familial lines of descent.
7.8 A simple branching diagram can be used to classify living and fossil groups of organisms by shared derived characteristics.
7.9 There are common ancestors to multiple related species (apes).

Earth and Space Sciences

8. Describe Earth's history.
   8.1 The Earth and the Moon formed approximately 4.6 billion years ago.
   8.2 The Earth's atmosphere originated from the escape of gas from the cooling Earth (outgassing) and later accretion of volatile materials from comets and asteroids. The Earth's atmosphere has changed in composition in geological time (oxygenation).
   8.3 Evidence from layers in the lithosphere (strata) allows for the ordering of events in Earth history (relative dating).
   8.4 The geologic time scale is divided into eras based on major changes in the forms of life present on Earth as observed in the fossil record (Archean, Proterozoic, Paleozoic, Mesozoic, Cenozoic).
   8.5 Geologic eras are divided similarly into periods (the Mesozoic Era is divided into the Triassic, Jurassic, and Cretaceous Periods).
   8.6 Tectonic movements over millions of years have caused major redistribution of continents and oceans across the Earth's surface both horizontally (continental drift) and vertically (mountain building, erosion).

9. Explain how the atmosphere (air), hydrosphere (water, snow, and ice), lithosphere (land), and biosphere (plants, animals, and humans) interact, evolve, and change.
   9.1 Distinctive interactions of the atmosphere, hydrosphere, and lithosphere are the basis of distinctive ecosystems, which include forests, deserts, swamps, savannas, grasslands, tundras, mountains, freshwater marine, and saltwater marine.
   9.2 Tectonic movements in the lithosphere play a role in sculpting the landscape (formation of mountain ranges, deep ocean trenches and rift zones, vulcanism).
   9.3 Wind plays a role in sculpting the landscape (aeolian processes) in environments including deserts and beaches (dunes, yardangs).

9.4 Water flow plays a role in sculpting the landscape, including groundwater flow, artesian wells, the dissolution of limestone (carbonate rocks), and the origin of caves and sinkholes.
9.5 Ice (glaciers) and snow (avalanches) play a role in sculpting the landscape (moraines, glacial till).
9.6 Fire, both natural and set by humans, plays a role in modifying the landscape.
9.7 The *biosphere* (plants, animals, and humans) modifies the interactions of hydrosphere, lithosphere and atmosphere in distinctive ways which may have positive or negative effects on the creatures living there (dam formation, stream channelization, forestry management).
9.8 Fossil fuels in the lithosphere are formed from decayed photosynthetic organisms (plants, algae, plankton).
9.9 Students will apply a knowledge of topography, climate, soils, and vegetation of **{State}**, the United States, and the world to understand how humans have modified and adapted to different physical environments.
9.10 Sources of energy and material used by humans are unevenly distributed across the Earth's surface, which accounts for the location of mining and industries to extract resources.

Technology and Engineering

10. We transmit ideas through communication technologies and systems. As a basis for understanding this concept, students know:
    10.1 How to identify and explain the components of a *communication system* (source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination).
    10.2 How to identify and explain the appropriate tools, machines, and electronic devices (drawing tools, computer-aided design, cameras) used to produce and/or reproduce design solutions (engineering drawings, prototypes, reports).
    10.3 How to identify and compare communication technologies and systems (audio, visual, printed, mass communication).
    10.4 How to identify and explain how symbols and icons (international symbols and graphics) are used to communicate a message.

11. Transportation technologies are systems and devices that move goods and people from one place to another across or through land, air, water, or space. As a basis for understanding this concept, students know:
    11.1 How to identify and compare examples of *transportation systems* and devices that operate on or in each of the following: land, air, water, and space.

11.2 How to explain a possible solution to a given transportation problem using the universal systems model.
11.3 How to identify and describe three subsystems of a transportation vehicle or device (structural, propulsion, guidance, suspension, control, support).
11.4 That there are five basic mechanical forces (lift, drag, friction, thrust, weight) which act on vehicles.
11.5 How the five basic mechanical forces (lift, drag, friction, thrust, weight) act on different vehicles (bicycles, scooters, skateboards, cars, boats, airplanes, rockets).

History of Science

12. Students learn about the contributions of nineteenth-century scientists to advance scientific knowledge and scientific reasoning, especially in the life sciences. Students will:
    12.1 Learn about nineteenth-century developments of scientific methodologies, such as William Whewell (hypothetico-deductive reasoning) and John Stuart Mill (inductive reasoning).
    12.2 Learn about the role of nineteenth-century scientists in the development of life sciences, such as Claude Bernard (experimental medicine), Jean-Baptiste Lamarck, Charles Darwin, and Alfred Russel Wallace (evolution), Louis Pasteur and Robert Koch (germs), and Rudolf Virchow (cell biology).
    12.3 Learn about the emergence of the nineteenth-century research university and its importance for the development of science.

Scientific Inquiry

13. Students should:
    13.1 Learn to assess the credibility of different sources.
    13.2 Determine what others have discovered about a phenomenon by reading grade-appropriate professional literature.
    13.3 Learn that researchers and citizens should develop their individual knowledge and judgment to assess the reliability of information on the internet and in printed sources.
    13.4 Learn and implement the steps of a scientific research project that combines background research and student investigation, including:
        13.4.1 identifying the scientific question, the sources in the literature, the relevant methods for investigation or testing, and the evidence necessary to test a question;
        13.4.2 conducting the scientific research project; and
        13.4.3 evaluating the strengths and weaknesses of the scientific research project's conclusions.

Grade Eight

Physical Sciences

1. Describe different patterns of motion of objects.
   1.1 The motion of an object is always judged with respect to some other object or point (frame of reference).
   1.2 The motion of an object can be described by its position, direction of motion, and speed.
   1.3 An object's motion is the result of the combined effect of all forces acting on the object. An object will remain at rest or continue moving in a straight line at constant speed unless acted upon by a net force.
   1.4 The change in position of an object with respect to time is its *velocity* and the change of the velocity of an object with respect to time is its *acceleration*. A change in velocity (*acceleration*) of an object occurs when there is a change in speed, change in direction, or both.
   1.5 The acceleration (a) of an object is related to its mass (m) and the applied force (F; $a = F/m$).
   1.6 For every action there is an equal and opposite reaction.
   1.7 The velocity and acceleration of a falling object can be measured using commonly available devices (slow-motion smartphone video).
   1.8 The position, speed, and acceleration of an object moving in one direction can be plotted using a computer spreadsheet.
   1.9 *Measurement uncertainty* limits the number of digits that can meaningfully be recorded in a measurement.
   1.10 Science uses the International System of Units (SI), also known as the MKS system, in which mass is expressed in kilograms, length is expressed in meters, and time is expressed in seconds. Some branches of science express mass in grams, length in centimeters, and time in seconds (CGS system).

1.10.1 SI units have a standard system of modifiers to express orders of magnitude variation in measurements (kilo = thousand, mega = million, giga = billion, milli = one thousandth, micro = one millionth, nano = one billionth). These modifiers are expressed in scientific notation (kilo = 10^3, mega = 10^6, giga = 10^9, milli = 10^{-3}, micro = 10^{-6}, nano = 10^{-9}.

1.10.2 The units in all terms of an equation must be dimensionally consistent.

1.10.3 Units can be multiplied and divided in the same way numbers are, which can be a useful method for analyzing physical phenomena (*dimensional analysis*).

2. Describe the effects of forces on the motion of objects.

2.1 *Force*, which can cause the motion of an object, may be expressed mathematically as a *vector*. A *vector* is defined by a magnitude and a direction which may be resolved into perpendicular components in a particular coordinate system.

2.2 Forces include *weight* (gravity acting on a mass), *applied* (push and pull), *normal* (contact), *compression*, *tension*, *electric*, *magnetic*, and *friction*.

2.3 When two or more forces are applied to an object simultaneously, the forces add up to one effective force known as the net force (resultant force).

2.4 When no net force is exerted on an object, it will either remain at rest or at constant speed in a straight line.

2.5 If the same net force is applied to two objects with different masses, the acceleration of the object with the smaller mass will be greater.

2.6 The orbits of planets in the solar system are governed by the force of the Sun's *gravity*. Gravitational force depends on the mass of the Sun, the mass of the planet, and the distance between them.

2.7 Every object exerts gravitational force on every other object. Orbiting objects (satellites, International Space Station) and projectiles are primarily influenced by the force of gravity.

2.8 Electric currents and magnets can exert a force on each other.

2.9 Machines transfer mechanical energy from one object to another.

2.10 Friction is a force that opposes motion or impending motion.

2.11 A machine can be made more efficient by reducing friction. Some common ways of reducing friction include lubricating or waxing surfaces.

2.12 The *normal force* from the surface balances (counteracts) the force of gravity on a static object sitting on a surface.

2.13 Force differs from *pressure* (force per unit area).

2.14 A force exerted on a small area exerts greater pressure than the same force exerted on a large area (icepick vs. snowshoe).

2.15 More force exerted on the same surface produces greater pressure (bicycle pump, inflation of a basketball).

3. Physical principles underlie biomechanics of movement and pressure.
    - 3.1 A lever is a simple machine for doing work which consists of a fulcrum, an inner lever arm, and an outer lever arm. In a lever, force exerted on the outer lever arm can produce a greater force at the inner lever arm (*mechanical advantage*).
    - 3.2 Levers exist in different types depending upon the relative placement of the fulcrum, outer lever arm, and inner lever arm (Types I, II, and III).
    - 3.3 Joints are the fulcrums of skeletal levers and may be utilized in Type I (neck), Type II (ankle), or Type III levers (elbow).
    - 3.4 Biological levers can be made of bone (endoskeleton), chitin (exoskeleton), or water (hydrostatic skeleton).
    - 3.5 Biomechanical pressures include static pressure (plants), hydrostatic skeletons (earthworms), and pressure-driven flow (hearts).
    - 3.6 Plants are held up by internal water pressure (turgor) and wilt when not given sufficient water to maintain turgor pressure.

4. Atoms possess a subatomic structure.
    - 4.1 The modern model of the atom has evolved over a long period of time through the work of many scientists.
    - 4.2 Each atom has a nucleus, with an overall positive charge, surrounded by one or more negatively charged electrons.
    - 4.3 The nucleus consists of one or more positively charged protons and neutrons with no charge. Electrons are negatively charged.
    - 4.4 The nucleus is held together by the strong (nuclear) force, which overcomes the repulsion between protons.
    - 4.5 In an *electrically neutral atom*, the number of protons equals the number of electrons. In an *ion*, the numbers of protons and electrons are not equal, giving the atom a net charge that is negative (*anion*) or positive (*cation*).
    - 4.6 The mass of any atom is expressed in terms of atomic mass units (amu) or daltons (Da). One atomic mass unit (amu) is defined as 1/12 of the mass of a carbon atom C-12 (6 protons and 6 neutrons). The mass of a proton or neutron in any atom is approximately equal to one atomic mass unit. An electron is approximately 1800 times less massive than a proton or a neutron.
    - 4.7 Two atoms with the same number of protons (atomic number, Z) and different numbers of neutrons are *isotopes* of the same element (C-12, C-13, C-14). Two atoms with the same number of neutrons (neutron number, N) and different numbers of protons are *isotones* (B-12, C-13). Isotopes of the same element are distinguished by their atomic mass number, A ($A=N+Z$). The mass of atomic isotopes will vary depending upon the number of neutrons in the nucleus.
    - 4.8 There are 92 naturally occurring elements and more than 25 elements have been artificially created.

Life Sciences

5. Observe and describe the variations in reproductive patterns of organisms, including asexual and sexual reproduction.
   - 5.1 Organisms reproduce asexually, sexually, or both sexually and asexually.
   - 5.2 There are many means of asexual reproduction, including division of a cell into two cells (fission), or separation of part of an animal or plant from the parent, resulting in the growth of another individual (regeneration, cutting, budding, fragmentation).
   - 5.3 Sexual reproduction involves the merging of sex cells (haploid gametes) to begin development of a new diploid individual. In many species, including plants and humans, eggs and sperm are produced.
   - 5.4 Merging of haploid gametes (fertilization) in organisms may be internal or external.
   - 5.5 The males produce small gametes (sperm) and the females produce large gametes (egg). The fertilization of an egg by a sperm results in a fertilized egg (zygote).
   - 5.6 In sexual reproduction, the haploid gametes (sperm and egg) each carry one-half of the genetic information for the new diploid individual. Therefore, the fertilized egg contains genetic information from both parents.
   - 5.7 In parthenogenesis, an embryo develops without fertilization by a sperm.
   - 5.8 In some plants, one individual can produce both male and female gametes (dioecy). In other plants, an individual may produce either male or female gametes (monoecy).

6. Different plants and animals have distinctive patterns of development (embryogenesis).
   - 6.1 The fertilized egg (zygote) undergoes numerous cellular divisions that transform it into a multicellular organism, with each cell having identical genetic information.
   - 6.2 During development from the zygote, multicellular organisms exhibit complex changes in form and function (development).
   - 6.3 During development, the cells derived from the fertilized egg differentiate into specialized tissues.
   - 6.4 In animal development, specialized cells organize into tissues, organs, and organ systems.
   - 6.5 During an organism's life cycle, various body structures and functions may change (metamorphosis, maturation).
   - 6.6 Patterns of development vary among animals. In some species the young resemble the adult, while in others they change form dramatically (metamorphosis).
   - 6.7 Patterns of development vary among plants. In seed-bearing plants, the embryo develops within a protective seed coat (angiosperm), or without a seed coat (gymnosperm). In non-seed-bearing plants, the embryo develops from single-celled spores (ferns, mosses).

Earth and Space Sciences

7. Describe the nature of volcanoes, earthquakes, plate tectonics, and the Earth's magnetic field.
    - 7.1 The interior of Earth consists of hot rock. Heat flow and movement of material within Earth cause sections of Earth's crust to move. This may result in earthquakes, volcanic eruptions, and the creation of mountains and ocean basins.
    - 7.2 The interior of the Earth consists of concentric layers (inner core, outer core, mantle) beneath the lithosphere.
    - 7.3 The hot molten rock in the Earth's mantle is known as *magma*. Volcanoes produce lava (molten rock at the surface). Volcanic eruption types include pyroclastic (stratovolcanoes, cinder cones) and fissure (shield volcanoes, mid-ocean ridges) eruptions.
    - 7.4 The Earth has a magnetic field, which is generated by the convection of the fluid outer layer of the metallic core. The magnetic field shields the Earth's surface from much of the deleterious effects of the Sun's solar wind (electrons, protons, alpha particles) and helps protect life on Earth.
    - 7.5 Anomalies in the movement of the Earth's fluid outer core cause the magnetic poles to reverse direction from time to time (paleomagnetism).
    - 7.6 Continents fitting together like puzzle parts, fossil correlations, and sea-floor spreading provided initial evidence of continental drift, and GPS measurements of plate motions have provided confirmatory evidence.
    - 7.7 *Plate tectonics* became a widely accepted theory to explain the evidence for continental drift, and explains how the solid lithosphere consists of a series of plates that float on the semi-solid (plastic) mantle. Convection cells within the mantle are the driving force for the movement of the plates.
    - 7.8 Plates may collide, move apart, or slide past one another. Most volcanic activity and mountain building occur at the boundaries of these plates, often resulting in earthquakes. Earthquake fault types include dip-slip (normal or reverse) and strike-slip (right-lateral or left-lateral).
    - 7.9 Folded, tilted, faulted, and displaced rock layers indicate past crustal movement.

8. Describe weather and its variability.
    - 8.1 The uneven heating of Earth's surface by sunlight is the primary cause of weather variations.
    - 8.2 The Equator-to-Pole temperature gradient and resulting atmospheric circulation create distinct climate patterns at different latitudes (equatorial, tropical, subtropical, temperate, polar).
    - 8.3 The rotation of the Earth causes distinct patterns of winds at different latitudes (Easterly Trade Winds, Mid-Latitude Westerlies, Polar Easterlies).

8.4 High-pressure (barometric) weather systems generally bring fair conditions. Low-pressure systems usually bring cloudy, unstable conditions. The general movement of highs and lows is from west to east across the United States.

8.5 *Air masses* (large areas of high barometric pressure) form when air remains nearly stationary over a large section of Earth's surface and takes on the conditions of temperature and humidity from that location.

8.6 The movement of air masses is determined by prevailing winds and upper air currents.

8.7 In mid-latitudes, which include the continental United States, weather conditions at a location are determined primarily by the temperature, humidity, and pressure of the air masses over that location.

8.8 For mid-latitude weather, *fronts* are boundaries between air masses. Precipitation is likely to occur at these boundaries.

8.9 In mid-latitudes, most changes in local weather conditions are caused by the movement of air masses and their interaction along fronts.

8.10 Four types of fronts exist: a cold front (when a cold air mass overtakes a warm air mass), a warm front (when a warm air mass overtakes a cold air mass), a stationary front (a front that has stalled and is stationary), and an occluded front (when a cold front overtakes a warm front).

8.11 In low latitudes (the tropics), one air mass dominates (the Equatorial air mass). Weather is formed because the barometric pressure increases with distance from the Equator and atmospheric pressure disturbances are created within this pressure pattern.

8.12 Hazardous weather conditions include thunderstorms, tornadoes, hurricanes, ice storms, and blizzards.

8.13 Greenhouse gases such as water vapor (the most important greenhouse gas), carbon dioxide, methane, and nitrous oxide affect weather and its variability. Dust from volcanic eruptions also can affect weather and its variability.

8.14 Space weather affects Earth (Northern and Southern Lights, electrical grid and communications disruptions).

Technology and Engineering

9. Manufacturing is the process of converting raw materials into physical goods via multiple industrial processes such as design, assembly, multiple stages of production, quality control, marketing, and distribution. As a basis for understanding this concept, students:

9.1 Describe and explain the manufacturing systems of custom fabrication, mass production through assembly lines and interchangeable parts (automobiles), and mass customization through robotics and 3D printing (dental prosthetics, small-batch manufacturing, prototyping).

9.2 Describe and explain the difference between discontinuous (*batch-wise*) and continuous chemical manufacturing processes.
9.3 Explain and give examples of the technological consequences of interchangeable parts, components of mass-produced products, computer-aided design (CAD), and the use of automation (robotics).
9.4 Describe a manufacturing organization (corporate structure, research and development, production, quality control, marketing, distribution).
9.5 Explain basic processes in manufacturing systems (measuring, cutting, shaping, assembling, 3D printing, joining, welding, finishing, quality control, and safety).
9.6 Explain the various ways in which a process can be automated (robotics, artificial intelligence, assembly lines).

10. Bioengineering technologies explore the production of mechanical devices, products, biological substances, and employ engineering principles with organisms to improve daily lives, prevent or treat disease, diversify energy sources, and more. As a basis for understanding this concept, students:
10.1 Explain examples of adaptive or assistive devices (prosthetic devices, wheelchairs, eyeglasses, grab bars, hearing aids, lifts, braces).
10.2 Describe and explain the manufacture of bioengineered products (food, medicines, bio-fuels).
10.3 Describe and explain ways in which plants and organisms can be used for mining (gold extraction) or environmental remediation (toxic metals, oil spills).
10.4 Describe and explain ways in which bioengineering can be used for agriculture or forestry (digital agriculture, soil management, integrated pest management, plant disease control).

11. Computer technology is used to analyze problems, aid in the design and manufacture of products, keep records, communicate (cell phones), locate (GPS), and permit machines to operate more efficiently. Students know that:
11.1 Computers consist of hardware (physical components) and software (computer programs) that manipulate digital information.
11.2 Digital information is based upon the binary number system (ones and zeros).
11.3 The smallest unit of computer data is a *bit*. It consists of a 0 or a 1.
11.4 A string of 8 bits is called a *byte*.
11.5 Digital information may be stored (RAM, ROM, etc).
11.6 Computers store data and process it according to instructions given to them by computer programs (software, apps, operating system).
11.7 Data are fed into a processor, which is controlled by software.
11.8 Software is written in code that translates an input to a user interface into digital (machine) language to control the processor.

- 11.9 Computers rely on digital inputs provided either by another digital computer or a person through an interface.
- 11.10 A processor outputs digital results through an interface (usually a GUI, sometimes to another digital device or machine).
- 11.11 Computer programs provide the instructions for computers to operate.
- 11.12 The instructions in a computer program are written in lines called *code*.
- 11.13 The lines of code are written in different computer languages (C++, Java, Python, R).

History of Science

12. Students learn about the contributions of twentieth-century scientists to advance scientific knowledge and scientific reasoning, especially in the physical sciences. Students will:
    - 12.1 Learn about twentieth-century developments of scientific methodologies, such as the rise of statistics (R. A. Fisher), computational modeling, "big data," and the reproducibility crisis (John Ioannidis).
    - 12.2 Know that twentieth-century scientists contributed to the development of quantum physics (Max Planck, Albert Einstein, Niels Bohr, James Chadwick, Marie Curie, Enrico Fermi, Otto Hahn, Lise Meitner, Ernest Rutherford, J. J. Thomson).
    - 12.3 Know that twentieth-century scientific industry, government support, and "big science" contributed to the development of science (General Electric Research Laboratory, Manhattan Project, DARPA, NASA, Bell Laboratories).

Scientific Inquiry

13. Students should:
    - 13.1 Conduct a scientific inquiry based upon analysis of *quantitative* data.
    - 13.2 Define and understand the difference between *precision* and *accuracy*.
    - 13.3 Plot quantitative data in a graphical format (manually, spreadsheet).
    - 13.4 Identify variables on a chart and recognize whether they are *independent*, *dependent*, or *correlated*.
    - 13.5 Determine the parameters of linear or non-linear relationships (polynomial, hyperbolic, exponential, logarithmic) using a spreadsheet program.
    - 13.6 Determine the slope of a line on a graph, and use dimensional analysis to express the slope in units appropriate to the data.

Scientific Inquiry – Grades Nine Through Twelve

Students should:

1. Know the intellectual presuppositions of scientific inquiry.
   - 1.1 The existence of objective, knowable truth about the natural world, the value of scientific inquiry, and the limits to its ability to discover truth.
   - 1.2 The universal truth of a scientific fact for *all* observers.
   - 1.3 Consideration of multiple causes and multiple working hypotheses.
   - 1.4 Openness to ideas from others that may seem counterintuitive or wrong.
   - 1.5 The need to make a case with evidence.
   - 1.6 Reporting all results, whether they support (positive) or refute (negative) a particular hypothesis.
   - 1.7 Recognition of biases as possible sources of error (blind faith in authority, tradition, or fashion, disregard of one's own fallibility, the misuse of words).
   - 1.8 Students of science must apply individual judgment not only about scientific conclusions but also about the process by which a researcher or professional community has come to them, since not all scientists follow best professional practices.

2. Know the ethical presuppositions of scientific inquiry.
   - 2.1 Science, like all human endeavors, can be prone to human fallibility, and is bound by ethical standards of practice, which scientists (including students) are obliged to respect.
   - 2.2 Protecting human subjects from harm, both physical and psychological (Ethics Review Boards).
   - 2.3 The importance of informed consent from human subjects, and the need to respect subjects' privacy.
   - 2.4 Sparing animal subjects from unnecessary suffering.

2.5 The importance of teamwork.
2.6 The importance of giving credit where credit is due.
2.7 The importance of intellectual charity, intellectual humility, and the desire to pursue truth rather than to win an argument.

3. Know how to design a scientific inquiry.
   3.1 Make and record observations of a natural phenomenon that you are curious about and raise questions based on those observations that will help explain the phenomenon.
   3.2 Research and study the relevant current and historical literature.
   3.3 Drawing on previous scientific knowledge and intuition, narrow down the question raised to formulate testable hypotheses with proper controls that could explain the phenomenon.
   3.4 Design a test of one of those hypotheses and choose appropriate equipment and methods to perform the test (further observation, controlled experiment).
   3.5 Estimate whether the precision and accuracy of the observations and measurements to be made are adequate to test the hypothesis.

4. Know how to conduct a scientific inquiry.
   4.1 Follow written directions to set up, use, and put away experimental equipment, including protective equipment and materials, safely, properly and responsibly.
   4.2 Learn to troubleshoot problems with experiments (leaks in chemistry equipment, short and open circuits in physics experiments).
   4.3 Use notes and computer spreadsheets to record systematically the equipment used, the procedures for making the measurements, and all observations and measurements.

5. Know how to analyze and interpret results.
   5.1 Use appropriate formats such as tables, plots and diagrams to display the observations and measurements made during the experiment. Make sure that they are properly labeled.
   5.2 Estimate the uncertainty in the measurements.
   5.3 Consider previous knowledge of scientific concepts which might help to interpret and explain the data.
   5.4 Use appropriate mathematical concepts from algebra, geometry, and trigonometry to analyze the data.
   5.5 Draw conclusions that are supported by the data.

6. Know how to communicate and apply results.
    - 6.1 Explain the conclusions and how the evidence supports them in writing and oral presentations.
    - 6.2 Discuss the limitations of the experiment, the results, the uncertainty in the data, and questions raised by the results.
    - 6.3 Suggest future investigations to extend or confirm results and answer questions raised by them.

7. Know how to write science research papers.
    - 7.1 Write clearly and concisely and avoid jargon.
    - 7.2 Write so that readers can grasp your results easily.
    - 7.3 State clearly in an abstract or summary what the paper reports and include a brief outline of the results.
    - 7.4 Give readers a clear indication of why the results are important.
    - 7.5 Give close attention to presentation of results and provide cogent and well-labeled tables, plots, diagrams, and illustrations.
    - 7.6 Give an honest and fair critique of the value of the conclusions reached and their relevance.
    - 7.7 Place your results clearly in the context of the relevant literature.
    - 7.8 Distinguish scientific evidence and conclusions from the social importance of those conclusions and focus upon scientific importance rather than social importance.

Physics – Grades Nine Through Twelve

All students should learn the unmarked standards. All students should be given the chance to learn the asterisked (*) standards.

1. Students can explain and predict different patterns of motion of objects.
    - 1.1 Measured quantities can be classified as either *scalar* or *vector*. A scalar has magnitude and is represented by a number.
    - 1.2 A vector is defined by a magnitude and a direction, and the vector may be resolved into perpendicular components in a particular coordinate system.
    - 1.3 The resultant of two or more vectors is determined by vector addition.
    - 1.4 *Position*, *velocity*, *momentum*, *acceleration*, and *force* are vectors. *Mass*, *distance* and *speed* (the magnitude of velocity) are scalars.
    - 1.5 Acceleration is the rate of change of velocity, which can be a change in speed, direction, or both.
    - 1.6 The momentum p of a moving object is the product of its mass m and velocity v: $p = mv$.
    - 1.7 Momentum is conserved in an isolated system (not subject to outside influences).
    - 1.8 The net force on an object is the vector sum of all the forces acting on the object.
    - 1.9 *Newton's First Law* states that an object will remain at rest or will move at constant speed in a straight line unless a nonzero net force acts on it.
    - 1.10 *Newton's Second Law* states that the force F on an object is the product of the object's mass m and acceleration a: ($F = ma$).
    - 1.11 A consequence of Newton's Second Law is that when the net force on an object is nonzero (unbalanced), the object will accelerate.
    - 1.12 According to *Newton's Third Law*, when one object exerts a force on another object, the second object exerts a force on the first that is equal in magnitude and opposite in direction.

1.13 *Impulse* is the average force (*F*) acting on an object multiplied by the time (Δt) over which it acts ($F^*\Delta t$). It is equal to the change in momentum (Δp) caused by the impulse.

1.14 *Kinetic friction* is a force that opposes motion, while *static friction* is a force opposing impending motion.

1.15 An object falling in a vacuum (*free fall*) experiences constant acceleration due to the force of gravity, and velocity increases continuously. The rate of fall under gravity in a vacuum is independent of mass and size.

1.16 The motion of an object falling through a fluid like air will be subject to a drag force, so that the actual motion will deviate from the theoretical motion it would have if gravity alone were acting upon the object (parachute). When the force of gravity equals the drag forces, velocity will be constant (*terminal velocity*). Terminal velocity increases with mass and size.

1.17 The path of a projectile is the result of the simultaneous effect of the horizontal and vertical components of its initial velocity and the force of gravity.

  1.17.1 A projectile's time of flight over a horizontal plane is dependent upon the initial vertical component of its velocity.

  1.17.2 The horizontal displacement of a projectile over a horizontal plane is dependent upon the initial horizontal component of its velocity and its time of flight.

1.18 Gravitational forces are only attractive, whereas electrical and magnetic forces can be attractive or repulsive.

1.19 Weight is the gravitational force with which a planet attracts a mass. The mass of an object is independent of the gravitational field in which it is located.

1.20 The elongation or compression of a spring depends upon the nature of the spring (its spring constant) and the magnitude of the applied force.

1.21 Normal force is the net force which produces normal acceleration. In uniform circular motion, the *normal force and normal velocity* are directed toward the center of the circle and are perpendicular to the tangential velocity.

1.22 The inverse square law applies to electrical and gravitational forces produced by point sources.

1.23 Newton's three laws are only approximations when speeds approach the speed of light or near very massive objects (Einstein's theories of Special and General Relativity).

2. Conservation of Energy and Momentum.

  2.1 Energy comes in many forms (mechanical, electrical, chemical, nuclear, thermal) and can be converted from one form to another. Energy is measured in joules.

  2.2 The energy of an isolated system (not subject to outside influences) is conserved.

2.3 The *potential energy* of an object is stored energy due to the object's position in an external field or its structure. Examples are gravitational (dammed water) and elastic energy (stretched or compressed spring).
2.4 The formula $PE = mgh$ defines the *gravitational potential energy PE* as equal to a mass m at height h above the Earth's surface, where g is the acceleration due to gravity at the Earth's surface.
2.5 *Kinetic energy* is the energy an object possesses by virtue of its motion.
2.6 The formula $KE = mv^2/2$ defines the *kinetic energy* of a point mass m moving at speed v.
2.7 In an ideal mechanical system (not subject to friction or damping), the sum of the kinetic and potential energies (*mechanical energy*) is constant.
  2.7.1 A mass spring system is an example of an ideal mechanical system that executes simple harmonic motion in which potential energy is converted into kinetic energy and back again during each cycle.
  2.7.2 That for a given spring constant (k) and mass (m), there is a natural frequency of oscillation (ω_n) equal to $\sqrt{(k/m)}$.
  2.7.3 *Resonance* is a steadily increasing amplitude that occurs when the mass spring system is forced at a frequency (ω) coinciding with its natural frequency (ω_n).
2.8 An object also can be characterized in terms of its *internal energy*, which is associated with its atoms and molecules and excludes the energy of motion of the object as a whole and of its energy due to its position in an external field, such as gravitational potential energy.
2.9 In a non-ideal mechanical system (subject to friction or damping), mechanical energy decreases and there is a corresponding increase in other energies such as internal energy.
2.10 When *work* is done on or by a system, there is a change in the total energy of the system.
2.11 Work done against friction results in an increase in the internal energy of the system.
2.12 Power is the time-rate at which work is done or energy is expended. Power is measured in watts (joules/second). One kilowatt = 1000 watts.

3. Electricity and Magnetism.
  3.1 Electricity and magnetism are fundamentally related.
  3.2 An electric charge is the source of an electric field E, a vector field.
  3.3 The magnitude of the electric field E at a distance r from a static point electric charge q is $q/(\epsilon_0 4\pi r^2)$, where ϵ_0 (electric permittivity of the vacuum) is a constant. For a positive charge, E is radially directed from the point charge; and for a negative charge, E is radially directed towards the point charge.

3.4 The electric force on a static point charge q is given by qE, where E is the electric field at the location of the point charge.
3.5 The force on a static point charge (q_1) from another static point charge q_2 at distance r is given by Coulomb's law: $F = q_1q_2/(\epsilon_0 4\pi r^2)$.
3.6 Moving electric charges and magnetized materials produce magnetic fields, which are vector fields.
3.7 An electric charge q moving at velocity v in a magnetic field B experiences a force of magnitude $qvB\sin\theta$ where v is the speed, B is the field strength (magnitude of the magnetic field) and θ is the angle between the vectors v and B.
3.8 The magnitude of the magnetic field around a straight wire carrying an electric current is given by Ampere's Law as $\mu_0 I/(2\pi r)$, where r is the distance from the wire and μ_0 (magnetic permeability of the vacuum) is a constant, and the direction is tangent to a circle of radius r, around the wire (right hand rule).
3.9 The magnitude of the magnetic field in the center of a circular current loop of radius R is given by the Biot-Savart Law as $\mu_0 I/(2R)$ and the direction is perpendicular to the plane of the loop.
3.10 A change in the magnetic field inside a current loop will induce a current in the loop.
3.11 Energy may be stored in electric or magnetic fields. This energy may be transferred through conductors or space and may be converted to other forms of energy.

4. Electric Circuit Theory.
   4.1 A circuit is a closed path in which a *current* can flow. There are two common types of circuit: *direct current* (DC), in which the direction of the current is constant, and *alternating current* (AC) in which the direction of the current alternates periodically in a sinusoidal pattern.
   4.2 A *resistor* limits current in a circuit, governed by *Ohm's Law*: $V = IR$ where I is the current flowing through the resistor, R is its *resistance*, and V is the voltage difference across the resistor. At room temperature most conductors obey Ohm's Law.
   4.3 *Resistivity* is a basic property of a material and is temperature-dependent. The *resistance* R is a property of an object of a material with resistivity (ρ), such as a cylindrical wire of particular cross-section area A and length L: $R = \rho L/A$.
   4.4 Circuit components may be connected in *series* or in *parallel*. In two components connected in series, the current is the same in both. In two components connected in parallel, the voltage across both is the same. Schematic diagrams are used to represent circuits and circuit elements.
   4.5 In a resistor with resistance R carrying a current I, electrical energy is converted to heat at the rate $P = I^2R$, where P is the power in watts.
   4.6 A *capacitor* is a circuit component that stores energy in an electric field. The simplest type of capacitor consists of two parallel plate conductors separated by an insulator.

4.7 An *inductor* is a circuit component that stores energy in a magnetic field. The simplest type of inductor is a wire coil.
4.8 Other circuit components are made from *semiconductors* to which small amounts of impurities have been added (*doping*) to lower their resistance at room temperature. The current in a doped semiconductor can be carried either by electrons (n-type) or by positively charged holes (p-type).
4.9 Semiconductor devices include *diodes* and *transistors*. Transistors can be used either as amplifiers (audio equipment) or switches (computers).
4.10 *Integrated circuits* contain a vast number of transistors and other components in a small area.

5. Waves.
5.1 Waves carry energy and information without transferring mass. This energy may be carried by pulse waves or periodic waves.
5.2 The characteristics of a wave include *amplitude*, *wavelength*, *frequency*, *period*, *wave speed*, and *phase*.
5.3 Mechanical waves require a material medium through which to travel.
5.4 Waves are categorized by the direction in which the amplitude varies relative to the direction of propagation of the wave, such as *transverse* and *longitudinal* waves.
5.5 *Sound* is a longitudinal mechanical wave in which the amplitude at any point is the pressure and the speed depends on the density of the medium, which can be a solid or fluid (liquid or gas).
5.6 *Electromagnetic radiation* consists of transverse waves that travel in a vacuum at the speed of approximately 3×10^8 meters/second or 186,000 miles/second.
5.7 The *electromagnetic spectrum* spans a broad range of wavelengths (radio, microwave, infrared, visible light, ultraviolet, X-rays, gamma rays).
5.8 Any electromagnetic wave traveling through matter can be *absorbed*.
5.9 When a wave strikes a boundary between two transparent media, *reflection* and *transmission* occur. A transmitted wave will be *refracted*.
5.10 When a wave moves from one medium into another, the wave may refract due to a change in speed. The *angle of refraction* (measured with respect to the normal) depends on the *angle of incidence* and the properties of the media (*indices of refraction*).
5.11 The absolute *index of refraction* of a medium is the ratio of the speed of light in a vacuum to the speed of light in the medium.
5.12 When waves of a similar nature meet, the resulting *interference* may be explained using the *principle of superposition*. *Standing waves* are a special case of interference.
5.13 *Diffraction* is the bending of light around an obstacle or through openings. The wavelength of the incident wave and the size of the obstacle or opening affect how the wave spreads out. Bright and dark fringes form, due to the principle of superposition.

5.14 When a wave source and an observer are in relative motion, the observed wavelength is shifted (*Doppler effect*).

5.15 An electromagnetic wave consists of electric and magnetic waves that propagate together. The electric wave and the magnetic wave are perpendicular (transverse) to the direction of propagation and to each other. The *polarization* of the photon is the orientation of its electric and magnetic waves.

6. Atomic structure and the interaction of light with matter.

6.1 In an atom, states of matter and energy are restricted to discrete values (quantized).

6.2 The charges of electrons (-1), protons (+1), and neutrons (0) are integer multiples of the elementary charge: 1.6×10^{-19} C.

6.3 In an atom, energy is emitted or absorbed in discrete packets of electromagnetic radiation called *photons*.

6.4 The energy of a photon is directly proportional to its frequency: $E = hf$ where h is Planck's constant (6.63×10^{-34} Js).

6.5 On the atomic scale, energy and matter exhibit the characteristics of both waves and particles.

6.6 According to Einstein's theory of special relativity, mass can be converted to energy and energy to mass ($E = mc^2$).

6.7 Among other things, mass-energy and charge are conserved at all levels (from subnuclear to cosmic).

6.8 Behaviors and characteristics of bulk matter are manifestations of its atomic structure. The macroscopic characteristics of matter, such as electrical and optical properties, are the result of the superposition of many microscopic interactions.

6.9 In the wave-mechanical model (electron cloud model) the electrons are in *orbitals*, which are defined as the regions of the most probable electron location.

6.10 Electrons, protons and neutrons have a quantized property called *spin* that can take either one of two equal and opposite values. Because of spin, all of these particles act like tiny magnets.

6.11 The orbital occupied by an electron in an atom determines its energy. Two electrons can occupy the same orbital if they have opposite spins.

6.12 When an electron in an atom gains a specific amount of energy, the electron moves to a higher energy state (excited state).

6.13 When an electron returns from a higher energy state to a lower energy state, a specific amount of energy is emitted. This emitted energy can be used to identify an element.

6.14 The outermost electrons in an atom are called the valence electrons. In general, the number of valence electrons affects the chemical properties of an element.

6.15 Atoms of an element that contain the same number of protons but a different number of neutrons are called *isotopes* of that element.

6.16 The average atomic mass of an element is the weighted average of the masses of its naturally occurring isotopes.

6.17 Stability of an isotope is based on the ratio of neutrons and protons in its nucleus. Although most nuclei are stable, radioactive nuclei are unstable and spontaneously decay, emitting radiation.

6.18 Spontaneous decay can involve the release of alpha particles, beta particles, positrons, and/or gamma radiation from the nucleus of an unstable isotope. These emissions differ in mass, charge, ionizing power, and penetrating power.

6.19 * The Standard Model of Particle Physics has evolved from previous attempts to explain the nature of the atom and states that:

6.19.1 Protons and neutrons are composed of subnuclear particles called quarks, which have charges that are a fraction of the elementary charge.

6.19.2 Each elementary particle has a corresponding antiparticle with an equal and opposite charge but the same mass and half-life.

6.19.3 The antiparticle of a photon is a photon with the same polarization, equal and opposite momentum, and 180 degrees out of phase.

6.20 *There are four fundamental forces of nature: gravity, weak, electromagnetic and strong.

6.20.1 The strong force holds the nucleus together.

6.20.2 The weak force is important in certain types of interactions and decays of nuclei and elementary particles.

6.20.3 Gravity is not included in the standard model, but the other three forces are.

6.20.4 The total effect of the fundamental forces is responsible for the appearance and behavior of the objects in the universe.

7. Explain nuclear transformations.

7.1 Nuclear transformations can be natural or artificial and include radioactive decay, neutron capture, nuclear fission, and nuclear fusion. When the result is the transformation of an element into one or more different elements, the transformation is called *transmutation*.

7.2 A radioactive isotope (radioisotope) has an unstable (parent) nucleus and will eventually decay spontaneously, sometimes changing into a different (daughter) element.

7.2.1 Many natural substances have radioactive isotopes, which may be found in very small quantities (0.01% of potassium in bananas).

7.3 *Half-life* is the time in which half of the initial number of identical parent nuclei of a radioisotope can be expected statistically to decay to their daughter nuclei.

7.4 *Radioactivity* (the number of particles emitted per second by a sample of identical radioactive isotopes) also decreases by half by the end of one half-life.

7.5 Radioactive decay can be used to date rocks, minerals, and remains of organisms.

7.6 There is a natural background radioactivity due to solar radiation, cosmic rays, and radioactive isotopes of natural substances, including rocks (granite) and gases (radon).

7.7 Radioactive isotopes have many beneficial uses in industrial chemistry and medicine for tracing chemical and biological processes, industrial measurement, nuclear power, and detection and treatment of diseases.

7.8 Transmutation of an element may occur naturally or can be induced by the bombardment of the nucleus with high-energy particles. Transmutation may occur through fission or fusion of nuclei.

7.9 Antimatter consists of antiprotons, antineutrons, and antielectrons (positrons). Matter and antimatter will annihilate each other.

7.10 Positron-emission tomography (PET) is a method of medical imaging that is based on the annihilation of electrons and positrons and their transformation into two gamma rays.

History of Science

8. The history of matter in motion is central to the history of physics. As a basis for understanding this concept, students know that:

8.1 In classical natural philosophy, the laws governing motion were tied in closely to Aristotelian theories of cause and effect, which were not based upon measurement or mathematics.

8.2 Galileo Galilei theorized that the acceleration of a mass was proportional to the applied force.

8.3 Isaac Newton invented mathematical tools (calculus) to develop his three laws of motion, and his universal law of gravitation, which related forces to the motion of any body from apples to planets moving through absolute Euclidean space and Newtonian time.

8.4 Albert Einstein sought to resolve inconsistencies discovered in the 19th century about the accuracy of Newton’s Laws of Motion concerning objects that move at speeds approaching the speed of light.

8.5 Einstein’s theory of special relativity recast Newton’s laws of motion so that time and space were no longer discrete variables as Newton saw them and postulated that space and time were actually a relative and unified space-time.

8.6 Niels Bohr developed quantum theory, which sought to resolve inconsistencies discovered using Newton’s Laws of Motion for the movement of electrons between atomic orbits.

8.7 Murray Gell-Mann and other physicists after World War II introduced the conception of the four fundamental forces and elaborated the laws governing the subatomic structure of matter (quarks).

9. Light and magnetism, long considered to be different phenomena, have been revealed to be different dimensions of the motion of electrons. As a basis for understanding the historical development of this concept, students know that:
   9.1 In classical natural philosophy, the laws governing light were described using the principles of geometry.
   9.2 Isaac Newton introduced his laws of motion to describe the refraction of light. This required light to be treated as a corpuscle. Newton required the ether to be wave-like to account for diffraction, and the corpuscles to have sides to account for polarization.
   9.3 Thomas Young and Augustin Fresnel found that refraction, diffraction, and polarization could be explained if light itself was a wave.
   9.4 James Clerk Maxwell combined the laws of electricity and magnetism and found that electricity moved at the speed of light, which led him to conclude that light was an electromagnetic wave.
   9.5 Einstein explained the photoelectric effect and fluorescence by postulating that light was a dimensionless particle that was described by numbers that represented frequency and wavelength.
   9.6 Twentieth-century physicists determined that photons and electrons have a quantum relationship.

10. In order to understand how nuclear reactions and the structure of the nucleus were discovered, students know that:
    10.1 Scientists discovered that the atom was not indivisible. Joseph John Thomson discovered that negatively charged corpuscles known as *electrons* within atoms could be split off from the rest of the atom, and Hantaro Nagaoka proposed and Hans Geiger, Ernest Marsden, and Ernest Rutherford found confirming evidence for a model of the atom where negatively charged electrons orbited around a positively charged *nucleus*.
    10.2 Niels Bohr's quantum theory predicted the arrangement of electrons surrounding the nucleus and that the outermost electrons determined an element's chemical properties.
    10.3 Henri Becquerel discovered that uranium salts exposed photographic plates in the dark; intrigued by Becquerel's findings, Marie Curie isolated the elements polonium and radium and coined the term "radioactivity".
    10.4 Scientists discovered different forms of radiation, including invisible *alpha rays* and *beta rays* emitted from uranium (Ernest Rutherford) and *gamma rays* emitted from radium (Paul Villard).
    10.5 Ernest Rutherford and Frederick Soddy discovered that radioactive atoms could be transformed into atoms of different elements.

10.6 Otto Hahn and Fritz Strassmann split the uranium atom by bombarding it with neutrons, producing the lighter element barium. Lise Meitner and Otto Frisch postulated that the uranium nucleus was split in two by *fission*, and Frisch realized that an enormous amount of energy would be released by fission according to Einstein's formula $E = mc^2$.

10.7 Nuclear physics, which includes nuclear fission and nuclear fusion, has been used to understand the nature of stars and to create technologies including medical imaging, nuclear medicine, biomedical research, radiodating, nuclear weapons, and power plants.

Scientific Inquiry

11. Classroom and Laboratory Instruction.

11.1 How to follow written procedures carefully to set up, operate safely, and put away all equipment, especially protective equipment, hot materials, electronic devices, and lasers.

11.2 How to apply algebra, geometry, and calculus to physics topics.

11.3 How to conduct and trouble-shoot laboratory experiments.

11.4 How to use measuring devices with accuracy and precision.

11.5 How to use equipment carefully to ensure its durability.

11.6 How to record results with videography, photography, fine draftsmanship and/or clear computer-aided graphics.

Chemistry – Grades Nine Through Twelve

1. Elements and the Periodic Table.
    1.1 Matter is composed of very small particles called *atoms*.
    1.2 There are 92 different types of naturally occurring *atoms*. These are called *elements*. There are also a number of artificially created *elements*.
    1.3 Each *element* has a unique number of *protons*, which is called its *atomic number. Protons* are positively charged and are located in the *nucleus* (core) of an atom along with *neutrons*, which are neutral in charge.
    1.4 *Electrons*, which are negative in charge, orbit the nucleus of an atom. In an electrically neutral atom, the number of *electrons* equals the number of *protons*.
    1.5 Each element has a fixed number of *protons* in its nucleus. The number of *neutrons* can vary, producing *isotopes* of the element. Each *isotope* has a fixed *isotopic mass,* which is approximately equal to the total mass of the *protons* and *neutrons* in its nucleus.
    1.6 Because different isotopes of each element exist in nature, the average *isotopic mass* of an element's *isotopes* on Earth is called the *atomic weight* of the element.
    1.7 If an *atom* has lost electrons, it is called a *positive ion* (*cation*). If it has gained electrons, it is called a *negative ion* (*anion*).
    1.8 A substance which consists of atoms from two or more elements bound together in fixed proportion is called a *compound*. Compounds comprise both *molecules* and *salts*.
    1.9 A *molecule* is a particle which consists of neutral *atoms* bound together in a fixed proportion. The fixed proportion is specified by the molecule's *molecular formula* (H_2, CO_2, SO_2, C_8H_{18}).
    1.10 A *salt* consists of anions and cations which are bound together in a fixed proportion. The fixed proportion is called the salt's *formula* ($NaCl$, H_2SO_4, $CaBr_2$).

1.11 The sum of the atomic weights of the atoms in a molecular or ionic substance's *formula* is called its *formula mass*. In the case of molecules, it may also be called the molecular mass.

1.12 One mole is 6.02×10^{23} particles (*Avogadro's number*). It is equal to the number of atoms in 12 grams of carbon-12.

1.13 The weight in grams of one mole of particles of a substance according to its *formula mass* is its *molar mass*.

1.14 The number of moles of a sample of a compound can be calculated from the sample's mass and its *formula*, and the number of molecules in a sample can be calculated from the sample's mass, its *formula* and Avogadro's number.

1.15 In the Periodic Table, the *elements* are arranged by their *atomic number,* and their chemical and physical properties, which include density, conductivity, malleability, solubility, and hardness.

1.16 The elements' different chemical properties determine their tendency to form various molecules and salts, each of which have their own physical and chemical properties.

1.17 Among the groups of elements that are arranged by their properties are the alkali metals, alkali earth metals, transition elements, noble gases, and halogens.

1.18 For Groups 1, 2, and 13-18 on the Periodic Table, elements within the same group (column) have the same number of valence electrons (helium is an exception) and therefore similar chemical properties.

1.19 The succession of elements within the same group (column) demonstrates characteristic trends: differences in atomic radius, ionic radius, electronegativity, first ionization energy, metallic/nonmetallic properties.

1.20 The succession of elements across the same period (row) also demonstrates characteristic trends: differences in atomic radius, ionic radius, electronegativity, first ionization energy, metallic/nonmetallic properties.

2. Pure Substances, Mixtures, and Solutions

2.1 A pure substance (element or compound) has a constant composition and constant properties throughout a given sample, and from sample to sample.

2.2 Mixtures are composed of two or more different substances. *Homogeneous* mixtures are uniform in composition. *Heterogeneous* mixtures are not uniform (oil in water). In heterogeneous mixtures small samples from different parts of the mixture may differ in their proportion of the substances contained in the sample.

2.3 The proportions of components in a mixture can be varied. Each component in a mixture retains its original properties.

2.4 Differences in properties such as density, particle size, molecular polarity, boiling and freezing points, and solubility often permit physical separation of the components of the mixture.

2.5 A *solution* is a homogeneous mixture of a *solute* dissolved in a *solvent*. The *solubility* of a solute in a given amount of solvent is dependent on the chemical natures of the solute and solvent, the temperature, and the pressure.
2.6 The concentration of a solution may be expressed in *molarity* (moles per liter), *molality* (amount of solute per mass of solvent), percent by volume, percent by mass, or parts per million (ppm).
2.7 The addition of a nonvolatile solute to a solvent changes the solution's *colligative properties*, including an increase of boiling point (boiling point elevation) and the decrease of freezing point (freezing point depression). The greater the concentration of solute, the greater the effect.
2.8 An electrolyte is a salt which, when dissolved in water, forms a solution capable of conducting an electric current. The ability of a solution to conduct an electric current depends on the concentration of ions.

3. Kinetic Theory.
 3.1 The *ideal gas* model explains the behavior of real gases. The ideal gas law is most accurate at low pressure and high temperature.
 3.2 Kinetic theory for an ideal gas states that all gas particles:
  3.2.1 are in random, constant, straight-line motion.
  3.2.2 are separated by great distances relative to their size, and the volume of the gas particles is negligible.
  3.2.3 have no attractive forces between them.
  3.2.4 experience collisions which may result in a transfer of energy and linear momentum between gas particles, but the total energy and linear momentum of the system remains constant.
 3.3 Temperature is a measure of the average kinetic energy (thermal energy) of the particles in a sample of material. It is measured in Kelvins (K).
 3.4 Pressure (force per area) is the force exerted per unit area on a surface by the random collision of gas atoms or molecules with that surface.
 3.5 The *ideal gas law* relates the pressure (P) and volume (V) of a gas through the *gas constant* (R) to the number of moles of gas (n) and the temperature (T) in Kelvins. The formula is $PV=nRT$.
 3.6 The random thermal motion of molecules drives diffusion.
 3.7 Diffusion is directional, and molecules diffuse from regions of high concentration to regions of low concentration.
 3.8 Equal volumes of gases at the same temperature and pressure contain an equal number of molecules.
 3.9 In a volume of gas, the total pressure is equal to the sum of the partial pressures of each of the constituent gases (Dalton's Law).

3.10 There are four states of matter: *gases*, *liquids*, *solids*, and *plasmas*. In a *gas* the atoms or molecules are negligibly attracted to each other and can move freely and independently of each other. In a *liquid* the atoms or molecules are more strongly attracted to each other and cannot move completely independently. In a *solid* the atoms or molecules are strongly attracted to each other and can only vibrate in place. A *plasma* exists at temperatures high enough to strip electrons from atoms, forming a mixture of ions, electrons and neutral atoms.

3.11 The four phases of matter (solids, liquids, gases, plasmas) have different properties.

3.12 Entropy is a measure of the randomness or disorder of a system. A system with greater disorder has greater entropy. Gases have higher entropy than liquids and liquids have higher entropy than solids.

3.13 Systems in nature evolve spontaneously from a state of higher energy to lower energy, and from a state of low entropy to high entropy.

3.14 Heat is the thermal energy transferred from a body of higher temperature to a body of lower temperature.

4. Types of Chemical Bonds.

4.1 The *valence* of an atom is the number of electrons it can share with another atom. An atom can have more than one valence (Fe^0, Fe^{2+}, Fe^{3+}).

4.2 The electrons of atoms reside in *shells* and subshells (orbitals) around the nucleus. The first shell ($1s^2$) can accommodate two electrons, the second shell ($2s^22p^6$) can accommodate eight electrons, and the succeeding shells can accommodate greater numbers of electrons. The outermost shell is known as the *valence shell*. When the valence shell is filled, the atom is stable.

4.3 A *metallic bond* arises from the electrostatic force between freely moving electrons and positively charged metal ions (Cu^0, Cu^{1+}, Cu^{2+}).

4.4 An *ionic bond* consists of the electrostatic force between two oppositely charged ions.

4.5 *Electronegativity* indicates how strongly the nucleus of an atom attracts electrons in a chemical bond. Electronegativity values are assigned according to arbitrary scales. Oxygen is a strongly electronegative element. Lithium is a weakly electronegative element. Carbon and hydrogen are moderately electronegative.

4.6 An *ionic bond* results from the very different electronegativities of the participating atoms.

4.7 A *covalent bond* results from the sharing of electrons between two atoms with similar electronegativities (C-N).

4.8 Covalent bonds are formed when two atoms with incomplete occupancy of shells share electrons to form a stable valence electron configuration. Noble gases have filled valence shells and stable valence configurations so they tend not to bond with other atoms.

4.9 Covalent bonds can be polar or nonpolar depending on how evenly the electrons are shared between the atoms. If there is a strong electronegativity difference between two bonded atoms, the bond formed has a *polarity*. In *polar* bonds the sharing is uneven; in *nonpolar* bonds the sharing is even or nearly so. The bonds in water (H_2O) are strongly polarized.

4.10 When a neutral atom gains one or more electrons, it becomes a negative *ion* and its radius increases. When a neutral atom loses one or more electrons, it becomes a positive ion and its radius decreases.

4.11 Electron-dot diagrams (Lewis structures) can represent the valence electron arrangement in elements, compounds, and ions.

4.12 In a single covalent bond, two electron pairs are shared between two atoms. In a double or triple covalent bond, four or six electron pairs respectively are shared between two atoms.

4.13 Metals tend to react with nonmetals to form *ionic compounds*. Nonmetals tend to react with other nonmetals to form molecular (covalent) compounds. Ionic compounds containing polyatomic ions have both ionic and covalent bonding.

4.14 Breaking a single chemical bond requires energy. Forming a single chemical bond releases energy.

4.15 A chemical reaction forms a new configuration of chemical bonds, the net effect of which may either release energy (exergonic), or absorb energy (endergonic).

4.16 Molecules may have a polarity determined by the shape of the molecule and internal distribution of charge. Symmetrical (nonpolar) molecules include CO_2, CH_4, and diatomic elements. Asymmetrical (polar) molecules include HCl, NH_3, and H_2O. Water is a strongly polarized molecule.

4.17 *Intermolecular forces* created by the unequal distribution of charge result in varying degrees of attraction between molecules. Hydrogen bonding is an example of an intermolecular force.

4.18 The *hydrogen bond* is a weak interaction between the hydrogen and oxygen atoms in different molecules (water, alcohols).

4.19 Physical properties of substances can be explained in terms of chemical bonds and intermolecular forces. These properties include conductivity, malleability, solubility, hardness, melting point, and boiling point.

5. Acids, Bases, and pH.

5.1 The acidity or alkalinity of an aqueous solution is measured by the pH scale.

5.1.1 The pH scale runs from 0 to 14. *Acidic solutions* have pH values less than 7; *basic solutions* (alkaline) have pH values greater than 7. Neutral solutions have a pH of 7 (water).

- 5.1.2 Acidic aqueous solutions have more H^+ ions than OH^- ions ($[H^+]/[OH^-] > 1$); basic solutions have more OH^- ions than H^+ ions ($[H^+]/[OH^-] < 1$); and neutral solutions have equal numbers of H^+ and OH^- ions ($[H^+]/[OH^-] = 1$).
- 5.1.3 The product of the hydrogen ion concentration and the hydroxide ion concentration equals 10^{-14}: $[H^+][OH^-]=10^{-14}$
- 5.1.4 The formula for the pH of a solution is pH = $-\log[H^+]$, where $[H^+]$ is the molarity of the hydrogen ions.
- 5.1.5 The formula for pH is logarithmic; therefore, each decrease of one unit in pH represents a tenfold increase in hydrogen ion concentration.

5.2 H^+ ions are called *hydrogen ions* (*protons*); OH^- ions are called *hydroxide ions*.

5.3 A hydrogen ion may also be written as $H_3O^+(aq)$, the hydronium ion (a hydrated proton).

5.4 pH meters and test strips can be used to determine the pH of a solution.

5.5 The behavior of many acids and bases can be explained by the Arrhenius definition.

- 5.5.1 *Arrhenius acids* yield $H^+(aq)$ ions as the only positive ion in an aqueous solution.
- 5.5.2 *Arrhenius bases* yield $OH^-(aq)$ ions as the only negative ion in an aqueous solution.
- 5.5.3 An Arrhenius acid and an Arrhenius base react to form a salt and water. This process is *neutralization*.

5.6 There are alternate general definitions of acids and bases.

- 5.6.1 The Brønsted-Lowry model defines an acid as a *proton* (H^+) *donor* and a base as a *proton* (H^+) *acceptor*. For example, the nitrogen atom in ammonia (NH_3) can accept a hydrogen ion (proton). Therefore, ammonia is a base.
- 5.6.2 The Lewis model defines acids and bases in terms of electron pairs. A Lewis base donates a pair of electrons while a Lewis acid accepts a pair of electrons.

6. Organic and Inorganic Compounds.

6.1 *Organic* compounds contain carbon atoms, which are bonded to hydrogen or one another in chains, rings, and networks to form a variety of structures.

6.2 *Inorganic* compounds are made of elements other than carbon, or if they contain a carbon atom, it is not bound to hydrogen or other carbon atoms (CO, CO_2, $NaCl$, $CaBr_2$).

6.3 *Hydrocarbons* are compounds that contain only carbon and hydrogen. Carbon atoms in hydrocarbons may be bound by single carbon-carbon bonds (saturated hydrocarbons). Carbon-carbon bonds in hydrocarbons may also be double bonds or triple bonds (unsaturated hydrocarbons).

6.4 Isomers of organic compounds have the same molecular formula, but different structures and properties.

6.5 Organic acids, alcohols, esters, aldehydes, ketones, ethers, halides, amines, amides, and amino acids are categories of organic compounds that differ in their structures. The structural difference between these different categories lies in the presence of distinct, covalently bonded groups of atoms called *functional groups.* These functional groups give each category of organic compound its unique chemical properties.

6.6 *Macromolecules* are large biological molecules, including natural *polymers* such as nucleic acids, proteins, and complex carbohydrates, and non-polymers such as lipids.

6.7 The building blocks (*monomers*) of complex carbohydrates are *sugars*.

6.8 The building blocks of nucleic acids are *nucleotides*.

6.9 The building blocks of proteins are *amino acids*.

6.10 Certain proteins, known as *enzymes*, act as catalysts in biochemical reactions.

7. Chemical Reactions, Conservation of Mass, and Balanced Equations.

7.1 In a *chemical reaction* the atoms in one or more substances (the *reactants*) rearrange to form different substances (the *products*).

7.2 In a *chemical reaction*, the *reactants* have different properties from the products.

7.3 Types of inorganic chemical reactions include *combination*, *decomposition*, *single replacement*, and *double replacement.*

7.4 Types of organic reactions include *addition*, *elimination*, *substitution*, and *rearrangement*.

7.5 An *oxidation-reduction* (*redox*) reaction involves the transfer of electrons (e^-). The number of electrons lost is equal to the number of electrons gained.

7.5.1 *Reduction* is the gain of electrons.

7.5.2 *Oxidation* is the loss of electrons.

7.5.3 An oxidation-reduction reaction is composed of two coupled *half-reactions*.

7.5.4 A half-reaction can be written to represent *reduction* ($Fe^{+3} + e^- \rightarrow Fe^{+2}$) or *oxidation* ($Fe^{+2} \rightarrow Fe^{+3} + e^-$).

7.6 An *oxidation state* is a number assigned to an atom to indicate the degree to which it has *oxidized* (+ *sign*) or *reduced* (- *sign*) (Fe in a 0, +2, or +3 oxidation state). An oxidation state of 0 indicates that the atom is electrically neutral; it has been neither oxidized nor reduced to form an ion.

7.7 An *electrochemical cell* is a device, containing an *anode*, a *cathode*, and a separating medium, in which *redox* (reduction-oxidation) chemical reactions occur. In an electrochemical cell, oxidation occurs at the anode and reduction at the cathode.

7.7.1 In *voltaic* (galvanic) cells a chemical reaction produces a current. A voltaic cell spontaneously converts chemical energy to electrical energy.

7.7.2 *Electrolytic* cells use a current to drive a chemical reaction. An electrolytic cell requires electrical energy to produce a chemical change. This process is known as *electrolysis*.

7.8 For all practical purposes, mass is conserved in chemical reactions (*Conservation of Mass*). In nuclear reactions mass is not conserved, but the total mass and energy is conserved ($E = mc^2$).

7.8.1 Dimensional analysis shows that the SI units of *E* are equal to the SI units of mass (*m*) times the speed of light (c) squared.

7.9 *Conservation of mass* greatly simplifies the balancing of chemical equations.

7.10 Chemical reactions are *balanced*, which means that the number and type of atoms participating in a reaction remain unchanged (conserved) even though the atoms rearrange.

7.11 The coefficients in a balanced chemical equation represent the mole ratios in the reaction.

7.12 With a balanced equation and the mass of one of the reactants or products, the mass of all the other reactants and products can be calculated.

7.13 Chemical reactions can either release heat (*exothermic* reaction) or absorb heat (*endothermic* reaction).

7.14 Energy released or absorbed during a chemical reaction can be depicted by a potential energy diagram.

7.15 Energy released or absorbed during a chemical reaction is equal to the difference between the chemical potential energy of the products and the reactants.

8. Chemical Reaction Rates and Equilibrium.

8.1 The *rate* at which a chemical reaction occurs depends on several factors: the nature of the reactants, the concentration of reactants and products, the temperature, the pressure, and the presence or absence of a *catalyst*.

8.2 Even though the products of a reaction may have lower chemical potential energy than the reactants, the reaction may occur slowly or not at all if there is a large energy barrier (*activation energy*).

8.3 The *activation energy* may be visualized as a hill of energy that must be surmounted by the reactants before they can run downhill to a lower potential energy.

8.4 Adequate thermal energy must be present to overcome the activation energy if a reaction is to proceed.

8.5 A catalyst lowers activation energy compared to an uncatalyzed reaction, by providing an alternative reaction pathway. This increases the reaction rate since the energy barrier is much smaller.

8.6 Some reactions can run in reverse, which means that the products react with one another to produce the original reactants.

8.7 All chemical reactions run until they reach equilibrium, which is the point at which the rate of the forward and reverse reactions are equal.

8.8 Many reactions are selected because they go to completion (irreversible reaction), which means the reverse reaction is negligible.

8.9 Le Chatelier's principle can be used to predict the effect on chemical reactions of perturbing (change in pressure, volume, concentration, and temperature) a system at equilibrium.

History of Science

9. The development of modern atomic theory updated and provided experimental support for the classical conception of matter as composed of a few types of infinitesimal atoms that combined to make the diverse types of matter. In order to understand how the structure of atoms was discovered, students will know that:
    - 9.1 In classical natural philosophy, Democritus proposed that there were only *atoms* and the *void*, and that all matter was composed of indivisible *atoms*.
    - 9.2 Antoine Lavoisier proposed that when materials reacted with each other the total amount of matter afterward must be the same as before (*conservation of mass*, *stoichiometry*).
    - 9.3 Antoine Lavoisier, Joseph Priestley, and Carl Wilhelm Scheele independently discovered a new element, oxygen; other scientists soon discovered many other distinct elements (Jöns Jacob Berzelius, Humphry Davy, and William Ramsay).
    - 9.4 John Dalton proposed that all matter consists of a vast number of extremely small atoms bound together by a *universal force of attraction* and opposed by an antagonistic *universal force of repulsion*, which was equivalent to *heat* (atomic theory).
    - 9.5 Nineteenth-century chemists elaborated the laws governing the physical behavior of gases and the relationship between molecular quantity and molecular weight, including Joseph Louis Gay-Lussac, Amedeo Avogadro, Émile Clapeyron, Thomas Graham, Rudolf Clausius, and Johannes van der Waals.
    - 9.6 Dmitri Mendeleev formulated the periodic table of the elements, which organized the elements on the table according to their properties, and allowed for prediction of the existence and the characteristics of undiscovered elements.
    - 9.7 Robert Bunsen and Gustav Kirchhoff discovered that different elements emit and absorb different spectra of electromagnetic radiation, leading to the development of spectroscopy, with applications from astronomy to biomedicine.
    - 9.8 Josiah Willard Gibbs clarified the thermodynamics of chemical reactions, making them predictable, and therefore useful for chemical industry.

10. The discipline of *organic* chemistry explores the chemistry of life in particular, which is essentially the chemistry of carbon. To understand how organic chemistry developed, students will know that:
    - 10.1 In classical natural philosophy, it was assumed that life and the synthesis of organic substances depended upon the operation of vital forces and essences that set life apart from the chemistry of the inanimate world (vitalism).
    - 10.2 19th-century chemists showed that certain organic compounds such as fats could participate in chemical reactions without invoking a vital force (Michael Chevreul), and that organic substances found in living things (e.g., urea) could be synthesized in the laboratory from inorganic materials independently of life (Friedrich Wöhler).

10.3 William Henry Perkins synthesized an organic dye (Perkin's mauve), sparking the synthetic dyes industry, which formerly had depended upon dyes harvested from rare living sources (cochineal, Tyrian purple).

10.4 Friedrich August Kekulé and Archibald Scott Couper discovered the bonding structures for carbon that made for the distinctive chemical properties of carbon compounds (benzene, double bonds, carbon ring, polymeric structures) and that made carbon the chemical foundation for life.

10.5 The chemical versatility of carbon ("organic chemistry") sparked many developments in medicine (aspirin, chemotherapy, synthetic vitamins), agriculture (fertilizers, pesticides, herbicides), chemical industry (dyes, textiles), and the petrochemical industry (aliphatic hydrocarbons, plastics, synthetic rubber).

10.6 Organic chemistry laid the foundation for *biochemistry*, which was dedicated specifically to the physical chemistry of life (metabolism, nutrition, reproduction, etc.)

10.7 Organic chemistry elucidated the material basis of the gene, consisting of chains of complementary base pairs in molecules of DNA (Chargaff's rules, DNA structure), which clarified the relationship between nucleotide sequence code and amino acid sequence code.

10.8 The chemistry of nucleotides was the foundation for the structure of genomes (polymerase chain reaction, PCR) and genetic engineering (CRISPR).

Scientific Inquiry

11. Classroom and Laboratory Instruction.

11.1 How to conduct and trouble-shoot laboratory experiments, especially leaks, contaminations, and other disruptions of controlled laboratory conditions.

11.2 How to apply algebra, geometry, and calculus to chemistry topics.

11.3 How to handle dangerous chemical substances.

11.4 How to use measuring devices with accuracy and precision.

11.5 How to use glassware and equipment carefully to ensure its durability.

11.6 How to follow written procedures carefully to set up, operate safely, and put away all glassware and equipment, especially protective equipment, bunsen burners, and dry ice.

11.7 How to record results with videography, photography, fine draftsmanship and/or clear computer-aided graphics.

Biology & Life Sciences – Grades Nine Through Twelve

1. Cellular life and homeostasis (the maintenance of life's dynamic disequilibrium) relies on a complex network of biochemical processes.
    - 1.1 Life requires a continuous input of energy, which originates mostly from sunlight, and is captured by photosynthesis in green plants (photoautotrophy).
    - 1.2 In limited circumstances, energy to support life originates from complex inorganic molecules (chemoautotrophy) rather than from the Sun.
    - 1.3 Photosynthesis in plant cells and some one-celled organisms occurs in the chloroplasts. Photosynthesis uses solar energy to combine the inorganic molecules carbon dioxide and water into energy-rich organic compounds (glucose). Oxygen is released to the atmosphere as a waste product.
    - 1.4 In all organisms, energy captured from light or chemicals is used to synthesize organic *monomers*, like sugars, amino acids, or nucleotides. These may assemble into complex *polymers*, such as starch or cellulose (sugars), proteins (amino acids) and nucleic acids (nucleotides). Energy also may be stored in complex lipids, including fats and oils.
    - 1.5 In all organisms, the energy stored in organic molecules may be tapped for cellular *respiration*, which consumes oxygen, and takes place in *mitochondria*. ATP (adenosine triphosphate) is the cell's "energy currency," which is used to power cellular work.
    - 1.6 ATP powers cellular work through the *ATP-ADP cycle*. ATP is synthesized from ADP (adenosine diphosphate) and phosphate. The breakdown of ATP is an *exergonic reaction* that makes energy available to power energy-requiring (*endergonic*) reactions, such as the synthesis of polymers, muscle contraction, nutrient uptake, waste removal, and secretion. ATP acts as a "refillable" energy store to power almost all cellular work.
    - 1.7 ATP also may be synthesized in the cytoplasm by *fermentation*, which does not require oxygen. Fermentation is a far less efficient way than respiration to synthesize ATP.

1.8 Biochemical processes, both breakdown and synthesis, are made possible by a large set of protein catalysts called *enzymes*. Enzymes accelerate the rates of chemical reactions and ensure that they occur in predictable and reliable ways.

1.9 The rate at which enzymes work can be influenced by internal environmental factors such as pH and temperature.

1.10 Enzymes and other molecules, such as hormones, receptor molecules, and antibodies, have specific shapes (configurations) that influence both how they function and how they interact with other molecules (*lock and key* model).

1.11 A complex network of biochemical reactions take place in a coordinated and interacting manner to sustain the dynamic disequilibrium necessary for life (homeostasis).

2. Cellular life depends on the cell's unique structure.

2.1 The cell's coordinated and complex functions are built around a common architecture shared by all cells.

2.2 All cells are bounded by a phospholipid bilayer membrane that contains embedded proteins (the *fluid mosaic model* of the membrane). Functions of the cell's plasma membrane include: separation of the cell's interior from the outside environment, controlling which molecules enter and leave the cell, and for sensory function, such as recognition of chemical (hormones, neurotransmitters) and physical (gravity, light) signals.

2.3 The plasma membrane is selectively permeable to molecules that dissolve readily in lipids (*hydrophobic*), and is relatively impermeable to molecules that dissolve readily in water (*hydrophilic*).

2.4 *Transport molecules* embedded in the plasma membrane manage the flows of hydrophilic materials across the membrane,

2.5 *Receptor molecules* in the plasma membrane play an important role in sensory interactions between the cell and the environment and between cells.

2.6 Substances may cross the plasma membrane in three ways: *diffusion*, in which a substance is transported down a concentration difference across the lipid portion of the membrane; *facilitated transport* (*facilitated diffusion*), in which a hydrophilic substance is transported down a concentration difference, via embedded membrane proteins; and *active transport*, in which an embedded protein uses the energy of ATP to transport a hydrophilic substance against its concentration difference.

2.7 The normal function of the cell depends upon many *reaction sequences* (glycolysis, Krebs cycle, Calvin cycle) that must take place in a coordinated manner.

2.8 Enzymes are protein *catalysts* that, by lowering the *activation energy* of a given reaction, facilitate certain *reaction sequences* in the cell over other potential reaction sequences, ensuring the reliable function of the cell.

2.9 Enzymes fold into complex forms (configuration) that work by bringing reactants into close proximity with one another at an *active site* where the chemical reaction can occur (*lock and key* model).

2.10 All cells store genetic information in chromosomes, which are single molecules of DNA. In *prokaryotic* cells (bacteria), the chromosome floats free in the cytoplasm. In eukaryotic cells (protists, fungi, plants, animals), the chromosomes are contained within a *nuclear envelope*.

3. Reproduction and development is essential for the continuation of all species.

3.1 Both organisms and *genomes* are reproduced.

3.2 *Mitosis* is a form of clonal reproduction that preserves the number of chromosomes (ploidy) from generation to generation.

3.3 Most eukaryotic cells are diploid. Diploid organisms differ from one another in the number of chromosomes (ploidy number): humans have 23 pairs of chromosomes (46 chromosomes in all).

3.4 Some organisms reproduce *asexually* by *binary fission* (prokaryotes) or *mitosis* (eukaryotes), with all the genetic information in the offspring coming from one parent. The offspring are genetically identical to the parents. Other organisms reproduce *sexually,* with half the offspring's genetic information typically contributed by each parent. None of the offspring are genetically identical to either parent.

3.5 *Meiosis* and fertilization are key to *sexual* reproduction. Meiosis results in the production of haploid gametes (sperm and ova), which each contain half of the parent's genetic information. During fertilization, gametes unite to form a diploid zygote, which comprises the complete genetic information for the offspring. In animals, meiosis only occurs in the *germ cells*.

3.6 The *phenotype* (*phenome*) is the expression of the *genotype* (*genome*), which is established at fertilization, as well as on environmental and cellular factors during development.

3.7 The zygote divides by mitosis to produce the *embryo*. During development, cells derived from the zygote *differentiate* to form the embryo's specialized cells, tissues, and organs (phenome), while retaining the common genotype (genome).

3.8 Populations of specialized cells in the organism known as *stem cells* are retained through the life of the organism, and retain the ability to differentiate into other types of cells. Stem cells are the basis of the organism's ability to heal from injury.

3.9 Human reproduction and development are influenced by gene expression, hormones (testosterone, estrogen, progesterone), nutrients (folic acid), and the health of the mother.

3.10 The structures and functions of the human female reproductive system produce large gametes (*ova*) in ovaries, allow for internal fertilization and internal development of the embryo and fetus in the uterus, provide oxygen, antibodies, and other essential materials through the placenta, as well as removal of carbon dioxide and other wastes. Nutrition and antibodies (*colostrum*) are provided for the infant through the mother's breast milk.

3.11 The structures and functions of the human male reproductive system produce small gametes (*sperm*) in testes and delivers sperm to the female's gametes for fertilization.

4. Traits are heritable characteristics that are transmitted from parent to offspring during reproduction.
    4.1 Heritable traits may be transmitted through genes that are arrayed on chromosomes.
    4.2 Genes are inherited, but their expression can be modified by interactions with the environment. Research in fields such as epigenetics and post-transcriptional splicing and editing complicates the relationship between DNA sequence (genotype) and gene expression (phenotype or trait).
    4.3 For offspring to resemble their parents, there must be a reliable way to transfer coded information from one generation to the next. Heredity is the passage of this information from one generation to another.
    4.4 An inherited trait of an individual can be determined by one or by many genes, and a single gene can influence more than one trait. A human cell contains tens of thousands of different genes in its nucleus.
    4.5 Genes may be transferred from one generation to the next through *vertical gene transfer*, from parent to offspring.
    4.6 Genes may also be transferred between species through *horizontal (lateral) gene transfer,* through hybrids, bacteria, and viruses.

5. Gregor Mendel established the rules of genetic inheritance through careful experiments with controlled crosses of pea plants.
    5.1 The Augustinian monk Gregor Mendel established the concept of the *particulate gene* through controlled breeding experiments on the inheritance of discrete traits, such as the height of a plant or the color of peas. Prior to Mendel, many scientists thought heritability *blended* the traits of both parents by some mechanism. What Mendel referred to as *factors* we now call genes.
    5.2 Mendel formulated the mathematics of inheritance based upon his concept of the particulate gene:
        5.2.1 *The principle of paired factors:* Plants carried two copies of genes for a trait. In a cross, the offspring would inherit one copy of the gene (*allele*) from the male, and one copy of the gene from the female.
        5.2.2 *The law of dominance:* Genes for a trait could exist as a *dominant* form and a *recessive* form. The dominant form would be expressed in a cross when both

genes were dominant, or when a dominant gene was paired with a recessive gene. Only when a recessive gene was paired with another recessive gene would the recessive trait be expressed.

5.2.3 *The law of segregation:* Gametes are formed by the *segregation* of one of the paired genes (*alleles*) of the parent. Each gamete receives one randomly chosen allele from each parent. Fertilization produces a zygote with paired genes, one from the male and one from the female.

5.2.4 *The law of independent assortment:* The genes for one trait will segregate into gametes independently of the genes for other traits.

5.3 A *pure-breeding* strain has identical paired genes for a trait.

5.4 A cross between pure breeding strains for a dominant trait and for a recessive trait will produce offspring (F1 generation) with ¾ of the offspring exhibiting the dominant trait, and ¼ expressing the recessive trait (Punnett Square analysis).

5.5 Mendel's mathematical principle of paired genes and laws of segregation were confirmed later by microscopical observation of reduction division (meiosis).

6. Mendel's laws of inheritance led to the modern conception of gene expression, embodied in the Central Dogma of Molecular Biology.

6.1 A *gene* may be considered as a delimited sequence in a molecule of DNA composed of four nucleotides: adenine (A), thymine (T), guanine (G), and cytosine (C).

6.2 A chromosome is a double-stranded structure consisting of two complementary DNA molecules bound together by weak attractive forces between *complementary base pairs*: adenine to thymine and guanine to cytosine. This makes each DNA molecule a complementary copy (*antisense replica*) of the other,

6.3 Each complementary copy of a DNA strand serves as a template to synthesize two new double-stranded replicas (*chromosome replication*).

6.4 In the nucleus, a gene's nucleotide sequence in DNA is transcribed into a complementary *transcript* composed of *ribonucleotides*: adenine (A), guanine (G), uracil (U) and cytosine (C). The transcript is known as messenger RNA (mRNA).

6.5 The coded sequence of ribonucleotides in mMRA is translated into a sequence of amino acids of a protein (*translation*) in *ribosomes* that reside in the cytoplasm. Each amino acid is coded by three consecutive ribonucleotides (*codon*) that bind an *anti-codon* in transfer RNA (tRNA). Each tRNA is associated with a specific amino acid.

6.6 Protein molecules are long polymers made from 20 different kinds of amino acids ordered in a specific sequence. Ribosomes synthesize proteins by adding specific amino acids to the end of a growing polypeptide chain. Ribosomes read the sequence of codons in the mRNA and add amino acids specified by associating the tRNA anti-codon with the specific mRNA codon.

6.7 The shape of a protein determines its function. The shape arises from a protein folding into *protein domains* (alpha helix, beta-pleated sheet) that are determined by weak interactions between amino acids.

6.8 The Central Dogma of Molecular Biology states that DNA replicates in all organisms, and that transcription from DNA to mRNA is always followed by translation from mRNA to protein. The Central Dogma also states that the process is always one way.

6.9 *Mutation* is an alteration of a gene's DNA sequence. Mutations are replicated along with replication of DNA, passing the mutation on to every cell that develops from it.

6.10 Mutation also includes other modifications of an individual's genome, including changes in DNA sequence, transposition of DNA between chromosomes ("jumping genes"), and replication and recombination errors.

6.11 The genetic information stored in DNA consists of tens of thousands of genes (*genome*), which direct the synthesis of tens of thousands of proteins (*proteome*) that express various traits (*phenome*).

6.12 In a diploid organism, genes exist as two *alleles*. Both copies of an allele may be identical (*homozygous*), or one may differ from the other (*heterozygous*).

6.13 In sexual reproduction, the two alleles of the offspring are derived equally from the haploid gametes of the male (paternal allele) and female (maternal allele). This was anticipated by Mendel's law of segregation.

6.14 Offspring resemble their parents because they inherit similar genes that code for the production of proteins that form similar structures and perform similar functions.

6.15 During embryonic development, specialized tissues arise to form the various organs of the body. All these tissues have the same genome as the zygote. Specialization occurs because of different patterns of gene expression in the different tissues.

6.16 An allele that would be deleterious in a homozygous individual may be maintained in a population by being carried by heterozygous individuals (*dominant-recessive)*.

6.17 Segregation errors lead to anomalous phenotypes (Down syndrome, Klinefelter syndrome).

7. Genetic engineering allows humans to alter the genetic makeup of organisms for agriculture, disease control, and pharmaceuticals.

7.1 Most varieties of cultivated plants and domesticated animals have been developed by selective breeding over many generations for particular traits (crop yield, milk quality, meat, disease and pest resistance).

7.2 New varieties of farm plants and animals can be developed by direct manipulation of genomes to produce new traits (genetic engineering).

7.3 Genetic engineering is done using specific enzymes to cut, copy, and move segments of DNA that may encode particular traits.

7.4 Viruses can be used to move particular segments of DNA into the genomes of other organisms, including bacteria.

7.5 Inserting, deleting, or substituting DNA segments can alter gene expression, either directly or indirectly, by changing how expression of other genes is regulated. An altered gene may be passed on to every cell that develops from it.

7.6 Knowledge of genetics is making possible new fields of health care; for example, finding genes which may have mutations that can cause disease will aid in the development of preventive measures to fight disease. Substances produced by genetically engineered organisms, such as hormones and enzymes, may reduce the cost and side effects of replacing missing body chemicals.

7.7 CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) technology can be used to modify selectively the DNA of living organisms.

8. Explain factors that limit growth of individuals and populations.

8.1 Energy flows through ecosystems, typically originating with sunlight, through photosynthetic organisms including green plants and algae, to herbivores, to carnivores, and to decomposers. This energy ultimately dissipates as heat into space.

8.2 Matter cycles among the biotic and abiotic components of the biosphere.

8.3 Earth effectively is a *closed system* that allows energy but not matter to cross its boundaries into its surroundings.

8.4 Cycling of matter is driven by energy fed into the Earth from the Sun. Carbon dioxide and water are combined by plants into carbohydrates and oxygen, which are then consumed to power metabolism and return matter to carbon dioxide and water (*carbon cycle*).

8.5 Both energy and matter flow through ecosystems through complex networks of exchange known as *food webs*. At each link in a food web, some energy is used to power metabolic work, and some is stored in newly made structures, but most is dissipated into the environment as heat. As a consequence, the amount of energy available to power metabolism diminishes from link to link in the food web.

8.6 Biomass and numbers of organisms diminish with each link in a food web. Thus, the biomass of photosynthetic plants (*primary productivity*) is greater than the biomass of primary consumers, which in turn is greater than the biomass of secondary consumers (like predators), with the biomass of decomposers being the least.

8.7 The biomass and number of organisms that any ecosystem can support is the *carrying capacity*, which may be limited by the available energy, water, oxygen, and minerals, and by the cycling of matter through the ecosystem.

8.8 The growth and survival of organisms in an ecosystem may depend on physical conditions including light intensity, temperature range, mineral availability, soil/rock type, and relative acidity (pH).

8.9 Organisms may modify environments to create suitable local environments (*niche construction*).

- 8.10 Organisms in an ecosystem live together (*symbiosis*) and interact in many ways. Some relations are mutually beneficial (*mutualism*). In some relations, organisms neither benefit nor are harmed (*commensalism*). Some relations benefit one organism but are detrimental to the other (*parasitism*, predator-prey, competition).

9. Explain the contribution of biodiversity to the dynamics of ecosystems.
   - 9.1 Ecosystems are sustained by complex networks (food webs) of *autotrophs* (self-feeders), *heterotrophs* (other feeders) and *saprotrophs* (rot-feeders).
     - 9.1.1 Autotrophs are *primary producers* and include *photoautotrophs* (photosynthesizing plants) and *chemoautotrophs* (bacteria that tap chemical potential energy).
     - 9.1.2 Heterotrophs are *consumers* of other living things and include *herbivores* (*primary consumers*) and various levels of *secondary consumers*, such as *predators* and carrion eaters, as well as various types of parasitic fungi and microorganisms.
     - 9.1.3 *Saprotrophs* are the ultimate consumers and are fungal or bacterial.
   - 9.2 An ecosystem is a community of interacting organisms inhabiting a physical environment. The physical environment can limit the ability of organisms to live there. Organisms also can shape the physical environment to their own adaptive needs.
   - 9.3 The organisms inhabiting an ecosystem may compete for vital resources.
   - 9.4 Organisms also may cooperate to enhance the availability of vital resources.
   - 9.5 Ecosystems can be stabilized over time through the emergence of networks of interdependent species (*climax ecosystem)* that both sustain one another and hold one another's populations in check.
   - 9.6 *Keystone species* provide essential functions for some ecosystems. In the absence of a keystone species, such ecosystems will change substantially.
   - 9.7 Ecosystems also may change rapidly over time, depending upon how species modify physical and biotic environments (*ecological succession*).
   - 9.8 Ecosystems, like many other complex systems, can show cyclic changes around a steady state (*predator-prey cycles*, disease prevalence).
   - 9.9 Ecosystems can be made resilient, through the activities of organisms (including humans), or in response to changes in climate (monsoon cycles, El Niño) or natural disasters (volcanic eruptions, floods, wildfires).

10. Evolution is the modification of species over time. There are many competing theories for the mechanism of evolution, although Neo-Darwinism is presently the prevailing theory.
    - 10.1 Darwinism is the theory that evolution works through *natural selection* for organisms with favorable traits that equip them for survival and reproduction.

10.2 Darwinism proposes that selection against unfavorable traits can lead to the extinction of species, that natural selection on existing species is a *continuous* and *gradual* process which produces new species over long periods of time, and that natural selection acts at the level of the organism.

10.3 Darwinism was changed by the early-20th century rise of genetics, including the conception of the Mendelian gene as a discrete unit of heredity.

10.4 Some scientists, like Thomas Hunt Morgan, argued that the discrete nature of the Mendelian gene was incompatible with continuous and gradual Darwinian evolution (mutationism).

10.5 Neo-Darwinism (the Modern Synthesis) reconciled Darwinian natural selection with Mendelian genetics through the theory of natural *gene* selection.

10.6 Natural *gene* selection is based upon statistical principles of *population genetics* that were developed in the early 20th century by population geneticists (Ronald Fisher, Sewell Wright, J.B.S. Haldane).

10.7 Neo-Darwinism proposes that *populations* are composed of interbreeding individual organisms that act as vehicles for Mendelian alleles that constitute a gene pool.

10.8 Mutations occur as random chance events. Gene mutations can also be caused by such agents as cosmic rays, radiation, and chemicals.

10.9 Neo-Darwinism recasts natural selection as differential survival of particular alleles within gene pools, and recasts evolution as changes over time of *allele frequency* in a gene pool.

11. Alternative theories of the mechanism of evolution have emerged that complement, modify, or substitute for Darwinism and Neo-Darwinism.

11.1 The Neo-Lamarckian concept, which is evolution through heritable adaptation (inheritance of acquired adaptations, epigenetics).

11.2 Morgan's *mutationism*, which asserts that evolution proceeds through genetic mutation, and not by natural selection.

11.3 Cuvier's *catastrophism*, which holds that evolution proceeds in abrupt environmental transitions interspersed with extended periods of stasis, and the modern evidence for catastrophic changes in the biosphere (asteroid impact, dinosaur extinction).

11.4 Goldschmidt's saltation concept (*hopeful monsters*), which holds that evolution proceeds in jumps due to large developmental changes.

11.5 Gould and Eldredge's concept of *punctuated equilibrium*, which describes the tempo of evolution as long periods of stasis (equilibrium) punctuated by abrupt changes in species composition as indicated in the fossil record.

11.6 Lovelock and Margulis' *Gaia hypothesis*, in which the Earth is a self-regulating organism shaped by *mutual and cooperative interactions* of its component organisms.

11.7 Odling-Smee's *Niche Construction Theory*, in which evolution is shaped by adaptation of environments to organisms.

11.8 Margulis' *endosymbiotic theory* (symbiogenesis), in which evolution occurs through the merger of different forms of life (origins of the mitochondrion and chloroplast).

11.9 The competing hypotheses for the origin of life on Earth, from non-living matter (*abiogenesis*) or from outer space (*panspermia*), including the difficulties posed by problems of self-replication, self-assembly, and autocatalysis.

11.10 The distinctions and similarities between the evidence and hypotheses about the origin of life (abiogenesis, RNA world, silicon-based life, self-organization) and the evidence and theories of evolution.

12. Important levels of organization for the body's structure and function include cells, tissues, organs, organ systems, and whole organisms.

12.1 Humans are complex multicellular organisms. They function through multiple interacting systems for digestion, respiration, reproduction, circulation, excretion, movement, coordination, and immunity.

12.2 The digestive system processes food, breaks down food into easily digestible parts, absorbs nutrients into the body, and processes solid wastes for elimination from the body, and:

12.2.1 consists of distinct organs (mouth, esophagus, stomach, small intestine, exocrine pancreas, liver, large intestine, gut microbiome, rectum);

12.2.2 assigns distinct functions (digestion, enzyme secretion, emulsification of fats, neutralization, absorption, synthesis) to these organs; and

12.2.3 processes food for absorption into the body as nutrients (carbohydrates, proteins, lipids, vitamins, minerals) and prepares waste for elimination from the body.

12.3 The pulmonary system mediates the exchange of the respiratory gases (oxygen and carbon dioxide) between the environment (atmosphere or water) and the blood, and:

12.3.1 consists of the nose, respiratory airways, lungs, respiratory muscles, and pulmonary components of the vascular system; and

12.3.2 exchanges oxygen and carbon dioxide between the air and blood.

12.4 The cardiovascular system pumps and distributes blood throughout the body, insuring the delivery of oxygen and nutrients to the cells, and gathering and eliminating carbon dioxide and wastes from the body, and:

12.4.1 consists of the heart, arterial vessels, capillaries, and venous vessels, which distribute oxygen and nutrients throughout the body and gather carbon dioxide and soluble wastes;

12.4.2 is subdivided into a pulmonary vascular system and systemic vascular system; and

12.4.3 uses a system of nodes that control and coordinate the action of the heart muscles to regulate the heartbeat.

12.5 The reproductive system mediates sexual reproduction by producing the gametes, and (in the human mother) providing a place for the fetus to grow and develop, and:

- 12.5.1 consists of the germinal organs (testes, ovaries), which produce the gametes;
- 12.5.2 supporting structures to convey sperm and eggs to their union (Fallopian tubes, vas deferens, uterus, prostate, urethra); and
- 12.5.3 in the female, uses structures to sustain the fetus during its development until birth (uterus, endometrium, placenta).

12.6 The fetus has a distinct physiology from the mother, which is mediated by:

- 12.6.1 the placenta, which manages the exchange of oxygen, carbon dioxide, nutrients and wastes between the mother and fetus;
- 12.6.2 the different patterns of circulation in the fetus that facilitate these exchanges; and
- 12.6.3 the changes of circulation, respiration, and immunity in the infant during and after birth.

12.7 The urinary system is responsible for managing the solute and water balance of the body, and clears soluble wastes from the blood, and:

- 12.7.1 consists of the kidneys, associated blood vessels, and bladder;
- 12.7.2 acts to filter wastes from the blood to produce urine; and
- 12.7.3 acts to regulate blood pressure within healthy limits.

12.8 The nervous system coordinates activities throughout the body with sensory information about the environment, and:

- 12.8.1 consists of the brain, brain stem, spinal cord, and autonomic, systemic, and peripheral nervous systems;
- 12.8.2 regulates sensation, cognition, communication, control, coordination, and motion;
- 12.8.3 communicates rapidly with different organ systems throughout the body through electrochemical impulses (action potential) transmitted through neurons, acting over very short times (seconds to minutes).
- 12.8.4 controls motion (motor systems) through motor neurons transmitting action potentials to the muscles of the musculoskeletal system; and
- 12.8.5 acts through *motor systems* to control other organs of the body, including activity of the gut and release of certain hormones.

12.9 The endocrine system consists of several glands that secrete hormones into the blood, and:

- 12.9.1 consists of several glands (pineal, hypothalamus, pituitary, thyroid, parathyroid, adrenal, endocrine pancreas, gonads), which secrete hormones for distribution through the blood;
- 12.9.2 cooperates with the nervous system, which indirectly controls some glands (neuroendocrine systems);

12.9.3 works in coordination with conditions of the body (glucose and the pancreas);
12.9.4 mediates communication between different parts of the body and coordinates the body's interactions with the environment; and
12.9.5 acts over extended time frames.

12.10 The immune system controls how the body responds defensively to environmental *antigens*, which can include disease-causing microorganisms, pollen, and certain foods, and:
12.10.1 consists of the skin (barrier immunity), white blood cells, bone marrow, lymphatic nodes, and the lymphatic system (humoral immunity);
12.10.2 mediates humoral immunity through antigen-specific antibodies that are created naturally in response to infection;
12.10.3 produces antigen-specific antibodies that act as a memory of past infection by novel antigens, and which can be produced rapidly in response to subsequent infections by the same antigen;
12.10.4 is stimulated and can be strengthened by exposure to natural antigens (dirt, dust);
12.10.5 is stimulated by vaccination to create antibodies to protect from future infectious diseases;
12.10.6 can be both benefited and harmed by antibiotics, which can both defend the body against infectious disease and disrupt microbial communities that are essential for healthy function (gut microbiome, skin microbiome); and
12.10.7 can produce auto-immune diseases (auto-immunity), in which immune systems treat the body's own cells as antigens (juvenile diabetes).

12.11 Viruses are vehicles for carrying genetic information (DNA and RNA) between cells and organisms. Viruses differ from cells in complexity and general structure, but they depend on cells for their replication.

History of Science

13. The history of biology has been shaped by differing philosophical approaches and advanced by technological developments that have allowed deeper exploration of the detailed nature of life. To understand how biology developed, students will know that:
13.1 The history of biology is an ongoing debate between those who believe that life is a solely material process (materialism, mechanism) and those who believe that life is a distinctive phenomenon (vitalism).
13.2 Classical Greek biology and medieval belief in the Great Chain of Being subscribed to vitalist notions of progress from inferior simplicity to superior complexity.

13.3 The invention of the microscope led to the discovery of the cell (Robert Hooke) and microorganisms (Antonie van Leeuwenhoek).

13.4 Cell theory proposes that the cell is the fundamental unit of life (Henri Dutrochet), and organismal theory proposes that the organism is the fundamental unit of life (Julius Sachs).

13.5 The development of molecular biology clarified the chemical basis of inheritance and development, including the discovery of DNA as the chemical basis of inheritance (Rosalind Franklin, Francis Crick, James Watson), the mechanism of replication, the genetic code, and the mechanism of translation.

13.6 Technological development of the microscope (higher-power lenses, phase contrast lens, electron microscopes) allowed scientists to explore the cellular and subcellular bases of life.

13.7 The early history of embryology was a debate between *preformationism* (the embryo develops from a pre-existing template) and *epigenesis* (the embryo is shaped by a vital force).

13.8 The development of embryology, which studies the formation of the organism from the zygote, has included contributions from and debates between advocates of organismal theory (physical factors, reaction-diffusion mechanisms) and of genetic theory (developmental algorithms).

14. A major component of biological inquiry has been directed toward acquiring knowledge about the structure of the human body, how to keep the body in good health, and how to prevent disease. To understand how knowledge of the human body developed, students will know that:

14.1 Classical Greek medicine was shaped by the Hippocratic conception of health and illness as states of balance and imbalance of contrary humors (blood, black bile, yellow bile, phlegm).

14.2 Galen, who was the principal authority in ancient and medieval Europe for Hippocratic conceptions of health and disease, dissected primates and assumed that humans had similar anatomy.

14.3 Andreas Vesalius used human dissection and anatomy to challenge many of the assumptions of Hippocratic medicine, while William Harvey used experimental anatomical knowledge and quantitative reasoning to establish the theory of the circulatory flow of blood in the body.

14.4 Vaccination was developed first to treat smallpox (Mary Wortley Montagu, Edward Jenner) and then applied to a widening number of infectious diseases, including yellow fever (Finlay, Reed) and polio (Salk, Sabin).

14.5 Ignaz Semmelweis proposed that, to prevent childbed fever, doctors should wash their hands to kill or remove germs after performing autopsies and before delivering a baby (germ theory of disease).

14.6 John Snow was the father of modern epidemiology, who used data collection to identify the source of an outbreak of cholera and whose discovery resulted in changes to water and waste systems.

14.7 Florence Nightingale pioneered the profession of modern nursing, as well as major achievements in applying epidemiology and statistics to health care.

14.8 Louis Pasteur correlated germs and disease, Robert Koch developed a method to show that germs cause disease, and Paul Ehrlich developed drugs that targeted germs and cured disease (Salvarsan).

14.9 Claude Bernard introduced rigorous scientific methodologies to the study of health and disease.

14.10 The discovery of antibiotics has made a major contribution to human health, including Alexander Fleming's discovery of penicillin and its subsequent mass production (Howard Florey, Ernst Chain).

14.11 The ability to rapidly sequence genomes of individual humans is leading to new insights into the genetic origins of disease.

14.12 New techniques in gene editing (CRISPR) are leading to new genetic therapies for heritable diseases, such as cystic fibrosis and sickle cell disease.

Scientific Inquiry

15. Classroom and Laboratory Instruction.

15.1 How to follow written procedures carefully to set up, care for, operate safely, and put away all equipment, especially protective equipment, microscopes, slides, needles, and scalpels.

15.2 How to apply mathematics to biology topics.

15.3 How to conduct ethical scientific inquiry on living organisms.

15.4 How to select the best organism to conduct a scientific inquiry.

15.5 How to determine the appropriate controls for a scientific inquiry.

15.6 How to keep organisms alive, using the correct nutrients (food, fertilizer, growth media) and sufficient and appropriate air, water, temperature, and light conditions.

15.7 How to use clean techniques to prevent contamination, including contamination of nutrients, air, and water.

15.8 How to use formula masses and algebra to weigh out solutes to mix solutions.

15.9 How to use a balance and a pH meter to prepare growth media.

15.10 How to conduct and trouble-shoot laboratory experiments, especially safe and gentle handling of living organisms.

15.11 How to handle dangerous chemical and biological substances.

15.12 How to use measuring devices with accuracy and precision.

15.13 How to use equipment carefully to ensure its durability.

15.14 How to record results with videography, photography, fine draftsmanship, and/or clear computer-aided graphics.

Earth & Space Sciences – Grades Nine Through Twelve

1. Explain complex phenomena, such as tides, variations in day length, solar insolation, apparent motion of the planets, and the annual traverse of the constellations and fixed stars across the sky.
   - 1.1 The eight planets and the dwarf planet Pluto move around the Sun in nearly circular orbits.
     - 1.1.1 The orbit of each planet is an ellipse with the Sun located at one of the foci.
     - 1.1.2 Earth is orbited by one moon and many artificial satellites.
     - 1.1.3 Pluto is a dwarf planet with a more elliptical orbit, which briefly places it within the orbit of Neptune during each revolution.
     - 1.1.4 There are many other dwarf planets orbiting the Sun, probably including many which have not yet been discovered.
   - 1.2 Most objects in the solar system are in regular and predictable motion.
     - 1.2.1 These motions explain such phenomena as the day, the year, seasons, phases of the moon, eclipses, and tides.
     - 1.2.2 Gravity influences the motions of celestial objects. The force of gravity between two objects in the universe depends on their masses and the distance between them.
   - 1.3 Earth's surface is mapped with a coordinate system of latitude and longitude, with the equator and prime meridian as reference lines. The coordinate system is based upon observations of the Earth's rotation, the Sun, and the stars.
   - 1.4 Earth rotates on an imaginary axis at a rate of 15 degrees per hour. To people on Earth, this turning of the planet makes it seem as though the Sun, the Moon, and the stars are moving around Earth once a day. Earth's rotation provides a basis for our system of time; meridians of longitude are the basis for time zones.
   - 1.5 The Foucault pendulum and the Coriolis effect provide evidence of Earth's rotation.
   - 1.6 Earth's changing position with regard to the Sun and the Moon has noticeable effects.

1.6.1 Earth revolves around the Sun with its rotational axis currently tilted at 23.5 degrees to a line perpendicular to the plane of its orbit, with the North Pole currently aligned with the star Polaris.

1.6.2 During Earth's one-year period of revolution, the relative orientation of the axis with respect to the Sun produces seasonal changes in the angle of incidence of the Sun's rays and length of the day (photoperiod) at a given latitude. These changes cause seasonal variations in the heating of the surface and seasonal variations in weather.

1.6.3 Seasons in particular locations arise from the angle of incidence and day length caused by the changing geometric relationship between the Earth on its tilted axis and the Sun. Diagrams and/or an *orrery* will illustrate the geometrical relationships.

1.6.4 Seasons in the northern hemisphere are opposite in phase to seasons in the southern hemisphere.

1.6.5 The vernal and autumnal equinoxes occur when the day and night are both 12 hours long. Spring and Summer have more than 12 hours of daylight and Fall and Winter have less than 12 hours of daylight.

1.7 Seasonal changes in the apparent positions of constellations and fixed stars provide evidence of Earth's revolution.

1.8 The Sun's apparent path through the sky (ecliptic) currently is tilted at an angle of 23.5 degrees relative to the orbital plane of the solar system at all times of the year, and its *azimuth* varies through the year with season.

1.9 Approximately 70 percent of Earth's surface is covered by a relatively thin layer of water, which responds to the gravitational attraction of the moon and the Sun with a daily cycle of high and low tides.

2. Describe current astronomical theories about the origin of the universe and solar system and describe characteristics of the solar system.

2.1 The universe is vast and estimated to be about 14 billion years old.

2.1.1 The scales of distance (orders of magnitude) of astronomical bodies (planets, solar systems, galaxies, galaxy clusters, galaxy superclusters, universe) show that the universe is vast.

2.1.2 The techniques for determining distance in the universe and the solar system include standard candles, parallax, and the lunar ranging retro reflector.

2.1.3 The current theory is that the universe was created from an event called the Big Bang. Evidence for this theory includes residual cosmic background radiation and a red-shift in the light from distant galaxies.

2.2 Stars form when gravity causes atoms and molecules (mostly hydrogen gas) to contract until nuclear fusion of light elements into heavier ones occurs. Fusion releases great amounts of energy and continues for millions of years.

- 2.2.1 Stars are classified by their surface temperature (color) and absolute magnitude (luminosity) (Hertzsprung-Russell diagram), which indicates where many stars are in their evolution of hydrogen fuel consumption.
- 2.2.2 The observed (relative) magnitude of a star is different from its absolute magnitude (luminosity). The ratio between the observed magnitude and the absolute magnitude of a star is used for making distance estimates with standard candles.
- 2.2.3 The universe contains billions of such galaxies. Our galaxy, which is called the Milky Way, is a *spiral galaxy* that contains billions of stars and spans a distance of 100,000 light years. Our Sun is a medium-sized star within the Milky Way, located about halfway between the center and the edge.
- 2.2.4 The Sun contains a core, convection zone, photosphere, chromosphere, and corona.
- 2.2.5 The nebular theory describes how suns and solar systems form.
- 2.2.6 Stars are the source of nearly all the elements in the universe (stellar nucleosynthesis).

2.3 Our solar system formed about five billion years ago from a giant cloud of gas and dust. Gravity caused Earth and the other planets to become chemically differentiated into concentric layers according to density differences in their materials. This process continues today, driving plate tectonics on Earth.

- 2.3.1 The characteristics of the planets of the solar system are affected by each planet's location in relation to the Sun.
- 2.3.2 The terrestrial planets (Mercury, Venus, Earth, Mars) are small, rocky, and dense. The Jovian planets (Jupiter, Saturn, Uranus, Neptune) are large, gaseous, and of low density. Icy bodies exist beyond the Jovian planets that are small, low density mixtures of rock and ice (Pluto and other dwarf planets).
- 2.3.3 A scale model of the solar system can be used to compare the relative sizes of the planets and the relative distances of the planets from the Sun.

2.4 Asteroids, comets, and meteorites also are components of our solar system (the Oort Cloud, the Kuiper Belt).

- 2.4.1 Asteroids, comets, and meteorites are remnant building blocks of the early solar system that continue to collide with other bodies.
- 2.4.2 The currently favored theory of lunar formation is that the Moon resulted from the collision of a Mars-sized body with the early Earth.
- 2.4.3 Impact craters can be identified in Earth's crust (Sudbury, Vredefort Impact Crater in South Africa, Meteor Crater).
- 2.4.4 Impact events have been correlated with mass extinction and global climatic change, as well as the location of some important mineral resources (Sudbury Impact Crater, Chicxulub).

- 2.5 The existence of planets and dwarf planets (Neptune, Pluto) in our solar system has been predicted using Newtonian physics, and the Kuiper Belt includes discovered and undiscovered dwarf planets.
- 2.6 Planets orbiting other stars (exoplanets) exist. Some exoplanetary solar systems vary from the model of our solar system.
- 2.7 Exploration of space has included human landings on the Moon (Apollo Program), direct sampling of the surface or atmospheres of several planets, a moon, asteroids, and a comet, and the use of terrestrial telescopes, space-based telescopes, and space probes.

3. Describe current theories about the history of Earth.
   - 3.1 Earth's early atmosphere formed as a result of the outgassing of water vapor, carbon dioxide, nitrogen, and lesser amounts of other gases from its interior.
   - 3.2 Earth's oceans formed as a result of precipitation over millions of years. The presence of an early ocean is indicated by sedimentary rocks of marine origin, dating back nearly four billion years.
   - 3.3 Earth has continuously been recycling water since the outgassing of water early in its history. This constant recirculation of water at and near Earth's surface is described by the hydrologic (water) cycle.
     - 3.3.1 Water is returned from the atmosphere to Earth's surface by precipitation. Water returns to the atmosphere by evaporation or transpiration from plants. A portion of the precipitation becomes runoff over the land or infiltrates into the ground to become stored in the soil or groundwater below the water table. Soil porosity influences these processes.
     - 3.3.2 The amount of precipitation that seeps into the ground or runs off is influenced by climate, slope of the land, soil porosity, rock type, vegetation, land use, and degree of saturation.
     - 3.3.3 Porosity, permeability, and water retention affect runoff and infiltration.
   - 3.4 Life has dramatically changed the composition of Earth's atmosphere. Free oxygen did not form in the atmosphere until oxygen-producing organisms evolved roughly two billion years ago. The ozone layer protecting Earth's surface from ultraviolet radiation required free oxygen in the atmosphere to form.
   - 3.5 The pattern of evolution of life-forms on Earth is at least partially preserved in the fossil record.
     - 3.5.1 Fossil evidence indicates that a wide variety of life-forms has existed in the past and that most of these forms have become extinct.
     - 3.5.2 Human existence has been brief compared to the expanse of geologic time and life's tenure on Earth.
   - 3.6 Geologic history can be reconstructed by observing sequences of rock types and fossils to correlate bedrock at various locations.

3.6.1 The characteristics of rocks indicate the processes by which they formed and the environments in which these processes took place.
3.6.2 Fossils of particular species of plants and animals restricted to particular environments provide information about past environmental conditions.
3.6.3 Geologists have divided Earth history into time units (eons, eras, periods, epochs) based upon the rock and fossil record.
3.6.4 Age relationships among bodies of rocks can be determined using principles of original horizontality, superposition, inclusions, cross-cutting relationships, contact metamorphism, and unconformities. The presence of volcanic ash layers, index fossils, and meteoritic debris can provide additional information.
3.6.5 The regular rate of nuclear decay (half-life time period) of radioactive isotopes allows geologists to determine the absolute age of materials found in some rocks.
3.6.6 Because of the rock cycle, the earliest formed rocks on Earth no longer exist and therefore cannot be dated.

4. Use the concepts of density and heat energy to explain observations of weather patterns and seasonal changes.
   4.1 Earth systems have internal and external sources of energy, both of which create thermal energy (heat).
   4.2 The transfer of heat energy within the atmosphere results in the formation of regions of different densities and, as a result, atmospheric circulation (motion) both vertically and horizontally.
   4.3 Weather patterns can be determined by observing, measuring, and recording weather variables. These variables include air temperature, atmospheric and barometric pressure, atmospheric moisture (relative humidity and dewpoint), precipitation (rain, snow, hail, sleet), wind speed and direction, and cloud type and cover.
   4.4 Observable patterns characterize atmospheric moisture, air temperature and atmospheric pressure distributions; jet streams; wind; air masses (anticyclones) and frontal boundaries; and the movement of cyclonic systems and associated tornadoes, thunderstorms, and hurricanes occur in observable patterns.
   4.5 Weather variables are measured using instruments such as thermometers (air temperature), barometers (atmospheric and barometric pressure), psychrometers and hygrometers (atmospheric moisture), precipitation gauges (rain, snow), anemometers (wind speed), wind vanes (wind direction) and LIDAR (cloud type and cover–LIght Detection And Ranging).
   4.6 RADAR (RAdio Detection And Ranging) is becoming frequently used to enhance weather prediction by allowing forecasters to see the radial velocity of winds and reflectivity from rain, snow, and hail.

4.7 Weather variables are interrelated (air temperature and atmospheric humidity affect atmospheric pressure and probability of precipitation and the atmospheric pressure gradient controls wind velocity both vertically and horizontally).

4.8 Weather variables can be represented in a variety of formats including radar and satellite images, weather maps (including station models, isobars, and fronts), atmospheric cross-sections, and computer models.

4.9 Air temperature, dewpoint, cloud formation, and precipitation are affected by the expansion and contraction of air due to vertical atmospheric movement.

4.10 Seasonal changes can be explained using concepts of incoming energy from the Sun, the Earth-Sun geometry, atmospheric density and barometric pressure variation, and thermal energy (heat). The seasonal changes include the shifting of global temperature zones, the shifting of planetary wind and ocean current patterns, the occurrence of monsoons, hurricanes, flooding, and severe weather.

4.11 The composition (chemicals) and physical structure (thermal, pressure) of the atmosphere affects the frequency and likelihood of weather events.

4.12 The chemical composition of the atmosphere drives its thermal structure, including the creation of vertical layers of the atmosphere (troposphere, stratosphere, mesosphere, thermosphere).

5. Use the concepts of density and heat energy to explain observations of the movements of Earth's plates.

5.1 Properties (density, mineral composition) of Earth's internal structure (crust, mantle, outer core, inner core) can be inferred from the analysis of the behavior of seismic waves (speed and direction, reflection and refraction).

5.1.1 Analysis of seismic waves allows the determination of the location of earthquake epicenters, and the measurement of earthquake magnitude; this analysis leads to the inference that Earth's interior is composed of layers that differ in composition and states of matter.

5.2 The outward transfer of Earth's internal heat powers tectonic processes that drive convective circulation in the mantle and which move the *lithospheric plates* at the Earth's surface.

5.3 The *lithosphere* consists of separate plates that ride on the more fluid *asthenosphere* and move slowly in relationship to one another, creating *convergent*, *divergent*, and *transform* plate boundaries. These motions indicate Earth is a dynamic geologic system.

5.3.1 These plate boundaries are the sites of most earthquakes, volcanoes, and young mountain ranges.

5.3.2 Compared to continental crust, ocean crust is thinner, denser, and younger. New ocean crust continues to form at mid-ocean ridges.

5.3.3 Earthquakes and volcanoes present geologic hazards to humans. Loss of property, personal injury, and loss of life can be reduced by effective emergency preparedness.

5.4 Many processes of the rock cycle are consequences of plate dynamics. These include the production of magma (and subsequent igneous rock formation and contact metamorphism) at both subduction and rifting regions, regional metamorphism within subduction zones, and the creation of major depositional basins through down-warping of the crust (Michigan Basin, Permian Basin).

5.5 Many of Earth's surface features such as mid-ocean ridges/rifts, trenches/subduction zones/island arcs, mountain ranges (folded, faulted, and volcanic), hot spots, and the magnetic and age patterns in surface bedrock are a consequence of forces associated with plate motion and interaction.

5.6 Plate motions have resulted in global changes in geography, climate, and the patterns of organic evolution.

6. Geomorphic Processes.

6.1 Landforms are the result of the interaction of tectonic forces and the processes of weathering, erosion, and deposition.

6.2 Different aspects of the Earth's surface can be represented with different kinds of maps and mapping tools.

6.2.1 Topographic maps represent terrain of landforms through the use of contour lines that are isolines connecting points of equal elevation. Gradients and profiles can be determined from changes in elevation over a given distance.

6.2.2 Geologic maps represent the rock types and structures interpreted to exist below the soil at the Earth's surface. Data for geologic maps come from direct sampling of outcrops for rock type, mineral content, orientation (strike/dip), and fossils where present. Data from geophysical techniques, including magnetic and gravitational data used to infer deeper structures, are also included on such maps. Geologic maps are inferred from such data as most of the rocky surface of the Earth is not exposed for direct investigation.

6.2.3 Satellite imagery (Google Earth, Geographic Information Systems) and aerial photography (LIDAR, drones) provide large-scale and comprehensive views of the Earth from above, which allows us to map Earth's surface and geology in innovative ways.

6.2.4 Sonar allows us to map the ocean floor and provided evidence for sea floor spreading/plate tectonics.

6.3 Climate variations, geologic structure, and mineralogical characteristics of bedrock influence the development of landscape features including plateaus, plains, valleys, ridges, escarpments, and stream drainage patterns.

6.4 Weathering is the physical and chemical breakdown of rocks at or near Earth's surface. Physical weathering mechanisms include frost wedging, wind abrasion, thermal expansion, and exfoliation while chemical weathering is dependent on moisture content, temperature and the mineral content of the material. Living organisms contribute to physical and chemical weathering via lichens, root growth, root exudates, feces/urine deposition, and digging . Soils are the result of weathering and biological activity over long periods of time. Climate is a major driver of weathering and is the dominant variable determining soil type.

6.5 Natural agents of erosion, generally driven by gravity, remove, transport, and deposit weathered rock particles. Each agent of erosion produces distinctive changes in the material that it transports and creates characteristic surface features and landscapes. In certain erosional situations, loss of property, personal injury, and loss of life can be reduced by effective emergency preparedness and land use decisions.

6.6 The natural agents of erosion include:

6.6.1 *Streams (running water):* Gradient, discharge, channel shape, and substrate influence a stream's velocity and the erosion and deposition of sediments. Sediments transported by streams tend to become rounded as a result of abrasion. Stream features include V-shaped valleys, deltas, flood plains, meanders, oxbows, and natural levees. A watershed is the area drained by a stream and its tributaries.

6.6.2 *Glaciers (moving ice):* Glacial erosional processes include the formation of U-shaped valleys, glacial striations in bedrock, glacial plucking, fjords, cirques, hanging valleys, kettles and kettle hole lakes, and finger lakes. Glacial depositional features include moraines, drumlins, eskers, kames, and outwash plains.

6.6.3 *Wave Action:* Erosion and deposition cause changes in shoreline features, including beaches, sandbars, spits, and barrier islands. Wave action rounds sediments as a result of abrasion. Waves approaching a shoreline at an angle result in sand movement parallel to the shore within the zone of breaking waves (long-shore current).

6.6.4 *Wind:* Erosion of and deposition of sediments by wind is most common in arid climates and along shorelines. Wind-generated features include dunes, yardangs, and sand-blasted bedrock.

6.6.5 *Mass Wasting:* Earth materials move downslope under the influence of gravity and is a major process in forming river valleys. Mass wasting causes significant economic harm to society, but can be mitigated by land use policies.

6.7 Patterns of deposition result from a loss of energy within the transporting system and are influenced by the size, shape, and density of the transported particles. Sediment deposits may be sorted or unsorted. Water and wind produce sorted sedimentary deposits, while mass wasting (rock slides) and glaciers produce unsorted deposits.

6.8 Sediments of inorganic and organic origin often accumulate in depositional environments. Sedimentary rocks form when sediments are compacted and/or cemented after burial or as the result of chemical precipitation from seawater.

7. Explain how incoming solar radiation and outgoing energy affect the climate of the Earth.
   - 7.1 The *energy budget* of the Earth consists of inputs of energy from the Sun and the loss of heat energy to space. Heat added from the Earth's core is trivial at the global scale, but may be influential at the local scale.
   - 7.2 The transfer of heat energy within the atmosphere, the hydrosphere, and Earth's surface occurs as the result of radiation, convection, and conduction, and the transport of evaporated water (latent heat).
   - 7.3 The incoming solar energy intercepted by a planet decreases rapidly with the distance of the planet from the Sun (inverse square law).
   - 7.4 *Insolation* (solar radiation) heats Earth's surface and atmosphere unequally due to variations in the intensity caused by differences in atmospheric transmissivity, transparency and the angle of incidence, and the duration of solar radiation which vary with time of day, latitude, and season.
   - 7.5 Characteristics of the materials absorbing solar energy (color, texture, transparency, state of matter, and specific heat) affect the amount of energy absorbed and how much the material warms.
   - 7.6 Different atmospheric gases, aerosols, and particles transmit, scatter, reflect, or absorb different parts of the electromagnetic spectrum (ultraviolet, visible light, near infrared).
   - 7.7 Much of the incoming ultraviolet radiation is absorbed by the ozone layer, which heats the stratosphere and helps trap water vapor in the troposphere.
   - 7.8 Some visible light is scattered and reflected by clouds while the rest is transmitted to the Earth's surface where it is either absorbed or reflected.
     - 7.8.1 The fraction of light that a surface reflects (*albedo*) varies depending on the material the light strikes.
     - 7.8.2 Atmospheric aerosols (natural and anthropogenic) scatter incoming light and cool the Earth's surface.
   - 7.9 The radiation absorbed at the Earth's surface is emitted to the atmosphere mostly as far infrared radiation (heat).
   - 7.10 Far-infrared radiation from Earth's surface is absorbed by "greenhouse gases" (water, carbon dioxide, methane, nitrous oxide) and scattered back to Earth. This effect raises the average temperature of the surface above what it would be in the absence of those gases.
   - 7.11 The effect of greenhouse gases on climate is ameliorated by latent heat transfer, convection, and advection of the Earth's atmosphere, biogeochemical cycles (photosynthesis, albedo modification and cloud formation), and ocean circulation. Significant positive and negative feedbacks between greenhouse gas concentrations, the biosphere, and climate exist.
   - 7.12 A far greater amount of energy flows through the physical system of the Earth than flows through the biosphere.

8. Explain how land masses and ocean currents affect weather and climate.
    - 8.1 A location's climate is influenced by latitude, proximity to large bodies of water, ocean currents, prevailing winds, vegetative cover, elevation, and mountain ranges.
    - 8.2 The effect of the rotation of the Earth (Coriolis Effect) has a significant effect on patterns of atmosphere and ocean circulation (Mid-latitude Westerlies, Polar Highs, Intertropical Convergence Zone) and climate.
    - 8.3 The Intertropical Convergence Zone and related latitudinal climate zones migrate with the seasons, affecting the distributions of precipitation and changes in cloud cover.
    - 8.4 The comparative distributions of land masses in the Northern and Southern hemispheres (continental predominantly in the North, oceanic predominantly in the South) leads to the two hemispheres having different climatic zone distributions.
    - 8.5 Land mass temperatures respond more rapidly (day versus night, winter versus summer) to changes in solar radiation than do the oceans (high specific heat of water vs. land), but oceans store considerably more heat than land masses. This is why the seasonal variation in temperature is greater in the northern hemisphere than the southern.
    - 8.6 Temperature and precipitation patterns are altered by natural events such as El Niño/La Niña (ENSO) events and volcanic eruptions.

9. Explain how and why Earth's climate changes over time.
    - 9.1 Climate changes continually at all time scales and Earth's climate has never remained constant.
    - 9.2 The Earth's climate has varied greatly between glacial advances and retreats that correlate with cyclical oscillations in Earth's orbit around the Sun (Milankovitch Cycles, precession).
    - 9.3 In addition to being affected by the climate, the biosphere also has a significant effect on the climate, including self-regulation and resiliency (carbon-oxygen cycle, hydrological cycle).
    - 9.4 Humans are just one of the many influences on Earth's climate (urban heat island effect, wetland drainage, deforestation, agriculture).
    - 9.5 Computer models of climate are simplified simulations of the real world, and make prognostications that are inherently uncertain.
    - 9.6 Global weather forecast models (short term) and climate models (long term) are quite different in their design, their strengths, weaknesses, value, limitations, and uncertainties.

10. Explain the properties of materials in terms of the arrangement and properties of the atoms that compose them.

- 10.1 Minerals have physical and chemical properties determined by their chemical composition and crystal structure.
  - 10.1.1 Minerals can be identified by well-defined physical and chemical properties, such as cleavage, fracture, color, density, hardness, streak, luster, crystal shape, and reaction with acid.
  - 10.1.2 Chemical composition, physical properties, and availability determine how minerals are used by humans.
- 10.2 Minerals are formed inorganically by the process of crystallization as a result of specific environmental conditions. These include:
  - 10.2.1 cooling and solidification of magma
  - 10.2.2 precipitation from water caused by such processes as evaporation, chemical reactions, and temperature changes
  - 10.2.3 rearrangement of atoms in existing minerals subjected to conditions of high temperature and pressure.
- 10.3 Rocks are composed of one or more minerals.
  - 10.3.1 Rocks are classified by their origin, mineral content, and texture.
  - 10.3.2 Conditions that existed when a rock formed can be inferred from the rock's mineral content and texture.
  - 10.3.3 The properties of rocks determine how they are used and also influence land usage by humans.

11. Carbon, oxygen, nitrogen and other elements flow between organisms and the environment.
    - 11.1 The components of the carbon cycle include the roles of photosynthetic producers (plants) and consumers (animals, fungi, bacteria).
    - 11.2 The components of the nitrogen cycle include nitrogen fixation, its energetic cost, and the role of bacteria in driving nitrogen between the atmosphere and plants.
    - 11.3 The components of the sulfur cycle include the cycling between minerals (gypsum) and bacteria.
    - 11.4 The components of the phosphorus cycle include weathering from sedimentary rocks, volcanos, fertilization of bacterial and algal growth due to runoff, and redeposition of phosphorus in sediments.

12. Geologic resources and hazards are not uniformly distributed across the Earth's surface; their uneven distribution creates variable wealth of natural resources and hazards among different countries, regions and states.
    - 12.1 Large amounts of mineral resources are needed to support human flourishing, requiring trade in materials between different nations to meet the needs of modern economies (iron, copper, nickel, rare earth elements, limestone, phosphorus, building stone, sand, gravel).

12.2 Large amounts of energy resources are needed to support human flourishing, requiring trade between different nations to meet the needs of modern economies (fossil fuels, wind, solar, geothermal, tidal, nuclear).
12.3 Modern technology requires increasing use of rare minerals found only in particular locations, whose limited supplies create strategic and economic barriers to their use.
12.4 The differing availability of minerals determines their price, with some resources at risk of being depleted within decades, without conservation or recycling.
12.5 The benefits of resource extraction (mining) must be balanced with costs (mine tailings, pollution, environmental degradation).
12.6 The location (global, national, state) and causes of major geologic and atmospheric hazards (volcanism, earthquakes, tsunamis, hurricanes, tornadoes, flooding).
12.7 Federal, state, and international agencies (United States Geological Survey, NASA, Environmental Protection Agency, International Joint Commission [Great Lakes]) all play roles in assessing, monitoring and mitigating hazards related to geologic and climatological sources. They also work to identify and safely extract mineral and energy resources and conduct site reclamation after extraction.

History of Science

13. The history of astronomy is central to the history of earth and space sciences. As a basis for understanding this concept, students know that:
    13.1 Classical astronomy's conception of the motions of the planets and heavenly bodies was built on the assumption that the Earth was the center of the universe (Ptolemy) and used mathematics as a descriptive tool rather than as a predictive one.
    13.2 Nicolaus Copernicus revived Aristarchus of Samos' theory that the Earth moved around the Sun.
    13.3 Johannes Kepler proposed that the motions of the planets around the Sun were not circles, but ellipses, contrary to classical ideas of planetary motion.
    13.4 Using newly developed instruments (the telescope), Galileo Galilei discovered that moons orbit around the other planets of the solar system and provided astronomical and mechanical evidence that the Earth moves around the sun.
    13.5 Isaac Newton used Galileo's mechanics to derive Kepler's elliptical orbits.
    13.6 Albert Einstein's theory of general relativity was used to predict that the universe could be either static or expanding.
    13.7 Edwin Hubble collected data on the positions and velocity of the galaxies to show the rate of expansion, and the age of the universe if the expansion began as a point.
    13.8 Twentieth-century astronomers increasingly use large scale arrays of antennas and electromagnetic radiation outside the visible light range (X-rays, ultraviolet light, infrared light, radio and microwave radiation) to explore the universe, including

discovery of cosmic background radiation, which provides evidence of the Big Bang (Arno Penzias and Robert Wilson), pulsars, (Antony Hewish and Jocelyn Bell), and exoplanets (Michel Mayor and Didier Queloz).

14. The history of the Earth has been marked by disputes over the age of the Earth and the rapidity of forces shaping it. To understand this idea, students know that:
    14.1 Some peoples around the world have believed the Earth was eternal and others have believed it was created in some fashion.
    14.2 James Hutton proposed, and Charles Lyell popularized, an alternate model (uniformitarianism) which proposed that the Earth was shaped by imperceptibly slow and continuous processes of erosion, and uplift, which could accommodate a conception of a very old Earth.
    14.3 William Thompson (Lord Kelvin) used his work on thermodynamics to estimate the age of the Earth as in the 10's to 100's of millions of years.
    14.4 Modern scientific evidence, including knowledge of heating of the Earth's interior by radioactive decay and dating of the age of rocks on Earth's surface, supports an estimate of the Earth's age of about 4.6 billion years.
    14.5 The corresponding shapes of many coastlines (South America and Africa's Atlantic coastlines, Southern Ocean coastlines of Australia and Antarctica) and other evidence led to the idea, proposed by Alfred Wegener, that continents moved on the surface of the earth (continental drift)—which was rejected or ignored by most of his contemporaries.
    14.6 Mounting evidence has transformed Wegener's concept of continental drift into the modern theory of plate tectonics; this evidence includes distribution of volcanoes and geothermal hot spots, paleomagnetic patterns correlated with age of formation of seafloor rocks, and recent GPS evidence of continental motions in real time.

15. The work of numerous geologists, physicists and chemists has contributed to our understanding of the atmosphere, oceans, and climate. As a basis for understanding this concept, students know that:
    15.1 John Herschel, Louis Agassiz, and Milutin Milankovic's work in the 1800's and 1900's established the existence of major ice ages and their correlation with cyclical perturbations of Earth's axis and orbit (Milankovitch cycles of precession, eccentricity and obliquity).
    15.2 Oceanography was founded on the results of 19th-century voyages of discovery (*Challenger* expedition), which provided detailed mapping of the ocean floors, discovered continental plate subduction zones and sea floor spreading, and gathered new data on distributions of temperature, salinity, chemistry, and motions of the Earth's oceans and atmosphere.

15.3 Svante Arrhenius, Eunice Foote and John Tyndall posited the existence of "greenhouse gases," including water vapor and carbon dioxide, which change how solar radiation and Earth cooling affect the Earth's climate.

15.4 Henry Stommel, Arnold Arons and Wally Broecker's discovered that global thermohaline ocean circulation is a major moderator of Earth's climate.

15.5 Paul Crutzen, F. Sherwood Rowland, and Mario Molina discovered the role man-made chlorofluorocarbons play in the production and depletion of ozone in the upper atmosphere of the polar regions, resulting in the first global treaty (Montreal Protocol) to remove a class of pollutants that affected atmospheric ozone.

Scientific Inquiry

16. Classroom and Laboratory Instruction.

16.1 How to follow written procedures carefully to set up, operate safely, and put away all equipment, especially protective equipment, hammers, sieves, loupes, telescopes, microscopes, and slides.

16.2 How to apply algebra, geometry, and calculus to earth and space science topics.

16.3 How to read and interpret topographic and geologic maps and star charts.

16.4 How to conduct soil chemistry experiments.

16.5 How to conduct and trouble-shoot laboratory experiments.

16.6 How to work in the field safely, including wearing appropriate clothing and awareness of fall risks and drowning risks.

16.7 How to handle dangerous minerals, dust, fibers, and acids.

16.8 How to use measuring devices with accuracy and precision.

16.9 How to use equipment carefully to ensure its durability.

16.10 How to record results with videography, photography, fine draftsmanship, and/or clear computer-aided graphics.

Technology and Engineering, High School

Learning Standards for a Full First-Year Course

Engineering concerns the theory and design of engines, machines, processes, and structures, while Technology concerns the implementation, application, operation, maintenance, and repair of engines, machines, processes, and structures.

Engineering Design

1. Students will demonstrate the ability to use the engineering design process to solve a problem. As a basis for understanding this concept, students:
    - 1.1 Understand that the engineering design process is used to solve problems and improve human welfare, identify examples of technologies, objects, and processes that have been modified to improve human welfare, and explain why and how they were modified.
    - 1.2 Identify and explain the steps of the engineering design process: identify the problem, research the problem, develop possible solutions, select the best possible solution(s), construct prototypes and/or mathematical models, test and evaluate, communicate the solutions, and optimize the design *iteratively* (by successive revision).
    - 1.3 Interpret plans, diagrams, and working drawings in the construction of prototypes or models.
    - 1.4 Interpret and apply scale and proportion to orthographic projections and pictorial drawings (¼” = 1’0”, 1 cm = 1 m).
    - 1.5 Use analog and digital techniques to produce and analyze multi-view drawings (orthographic projections) and pictorial drawings (rendering, isometric and oblique perspective).

Construction Technologies

2. Students will use construction technology to build and construct either full-size models or scale models using various materials commonly used in construction. As a basis for understanding this concept, students:
   - 2.1 Identify concepts of construction technology, including preparing a site, setting a foundation, erecting a structure, installing utilities, and finishing a site.
   - 2.2 Identify and demonstrate the safe and proper use of common hand tools, power tools, and measurement devices used in construction.
   - 2.3 Know how measurement devices are used to improve accuracy.
   - 2.4 Identify and explain the engineering properties of materials used in structures (elasticity, plasticity, R value, density, strength).
   - 2.5 Distinguish among tension, compression, shear, and torsion, and explain how they relate to the selection of materials in structures.
   - 2.6 Explain the effect of Bernoulli's principle on structures such as buildings and bridges (wind effects).
   - 2.7 Calculate the resultant force(s) from a combination of dead loads (permanent), live loads (temporary), and environmental factors (tornados, earthquakes, tsunamis, hurricanes, floods).
   - 2.8 Recognize the purposes of zoning laws and building codes in the design and use of structures.

Energy and Power Technologies—Fluid Systems

3. Students will use the engineering design process to solve a problem in a fluid system. As a basis for understanding this concept, students:
   - 3.1 Know that fluids are any flowing material, including gases, liquids, and fluidized solids.
   - 3.2 Identify systems that transport fluids, with associated pressures and velocities; and serve functions such as providing water, gas (natural gas), oil, heating, ventilation, and air conditioning (HVAC), and removing waste.
   - 3.3 Explain the basic differences between *open* fluid systems (irrigation, forced hot air system, air compressors) and *closed* fluid systems (forced hot water system, hydraulic brakes).
   - 3.4 Explain the differences and similarities between hydraulic and pneumatic systems, and explain how each are used in manufacturing and transportation systems.
   - 3.5 Calculate and describe the ability of a hydraulic system to multiply distance, multiply force, and effect directional change.

3.6 Recognize that the relationship between pressure and flow through a pipe is governed by Poiseuille's Law, which specifies the relationship between pipe radius, pipe length, fluid viscosity, and mass flow.
3.7 Recognize that Bernoulli's equation is the law of conservation of energy applied to fluids, both flowing and static (hydrostatic pressure, dynamic pressure, wall pressure).
3.8 Identify and explain sources of resistance (45° elbow, 90° elbow, changes in diameter) for water moving through a pipe.

Energy and Power Technologies—Thermal Systems

4. Students will use the engineering design process to solve a problem in a thermal system. As a basis for understanding this concept, students:
    4.1 Identify thermal systems which transfer heat in order to control a given environment (room temperature) or do mechanical work (steam engine).
    4.2 Differentiate among modes of heat transfer (conduction, convection, and radiation) in a thermal system (cooking, forced-air heating and cooling, solar heating).
    4.3 Examples of how conduction, convection, and radiation are considered in the selection of materials for buildings (insulation, window design).
    4.4 How environmental conditions such as wind, solar angle, and temperature influence the design of buildings (vernacular architecture, biomimetic architecture).
    4.5 Identify and explain the costs and benefits of using renewable and nonrenewable energies (fossil fuels, nuclear energy, hydropower, wind and solar energy conversion systems) for providing power for thermal systems.

Energy and Power Technologies—Electrical Systems

5. Students will use the engineering design process to solve a problem in an electrical system. As a basis for understanding this concept, students:
    5.1 Identify electrical systems as generating, transferring, and distributing electricity.
    5.2 Compare and contrast alternating current (AC) and direct current (DC) circuits, and give examples of each.
    5.3 Use Ohm's law to explain the relationships among voltage, current, and resistance in a simple DC circuit.
    5.4 Explain how to measure and calculate voltage, current, resistance, and power consumption in a series circuit and in a parallel circuit.
    5.5 Understand how capacitance and inductance affect current flow in AC circuits.
    5.6 Identify the instruments used to measure voltage, current, power consumption, and resistance.

5.7 Identify and explain the components of a circuit, including sources (batteries, generators, alternators, transformers), conductors, circuit breakers, fuses, controllers (switches, relays, diodes, variable resistors), and loads.
5.8 Recognize that the stable functioning of electric grids depends upon baseline power, surge power, storage capacity, and the technologies required to support them.

Communication and Information Technologies

6. Students use the engineering design process to solve a problem in communication and information technology. As a basis for understanding this concept, students:
   6.1 Differentiate between analog and digital signals.
   6.2 Understand how analog and digital signals are converted from one form to the other.
   6.3 Identify ways in which information can be encoded, including analog signals, digital signals, symbols, measurements, icons, and graphic images.
   6.4 Describe the use of digital and analog technologies in communication and information systems (computers, cell phones).
   6.5 Explain how the various components (source, encoder, transmitter, receiver, decoder, destination, storage, retrieval) and processes of a communication system function.
   6.6 Explain how information travels through the following media: electrical wire, optical fiber, air, water, and space.
   6.7 Identify and explain the applications of laser, fiber-optic, and microwave technologies (telephone systems, cable television, medical imaging).
   6.8 Explain the application of electromagnetic signals in fiber optic technologies, including critical angle and total internal reflection.
   6.9 Know that information is subject to degradation, and the ways information systems deal with this (repeaters, amplifiers, cable design).

Agriculture Technologies

7. Agriculture is an increasingly technical field that relies on advanced mechanical, digital, process, and bioengineering principles. As a basis for understanding this concept, students:
   7.1 Describe the uses of technology in agriculture, including power, construction, nutrition, flavor enhancement, soil and water conservation, hydroponics, irrigation, pest and fungal control, waste management, breeding, genetic engineering, harvesting, storage, and food processing.
   7.2 Describe the costs and benefits of organic, sustainable, and other nontraditional forms of farming.
   7.3 Describe the uses of technology in aquaculture, including fish ponds.

Manufacturing Technologies

8. Students use the engineering design process to solve a problem in manufacturing technology. As a basis for understanding this concept, students:
   - 8.1 Describe the manufacturing processes of casting and molding, machining, forming, separating, conditioning, assembling, and finishing.
   - 8.2 Understand the concept of additive manufacturing (3D printing) and how it differs from other manufacturing processes.
   - 8.3 Describe the advantages of using computer control and robots (robotics) in the automation of manufacturing processes (increased production, mass customization, quality assurance, safety).
   - 8.4 Identify the criteria necessary to select safe tools and procedures for a manufacturing process (properties of materials, required tolerances, end-uses).