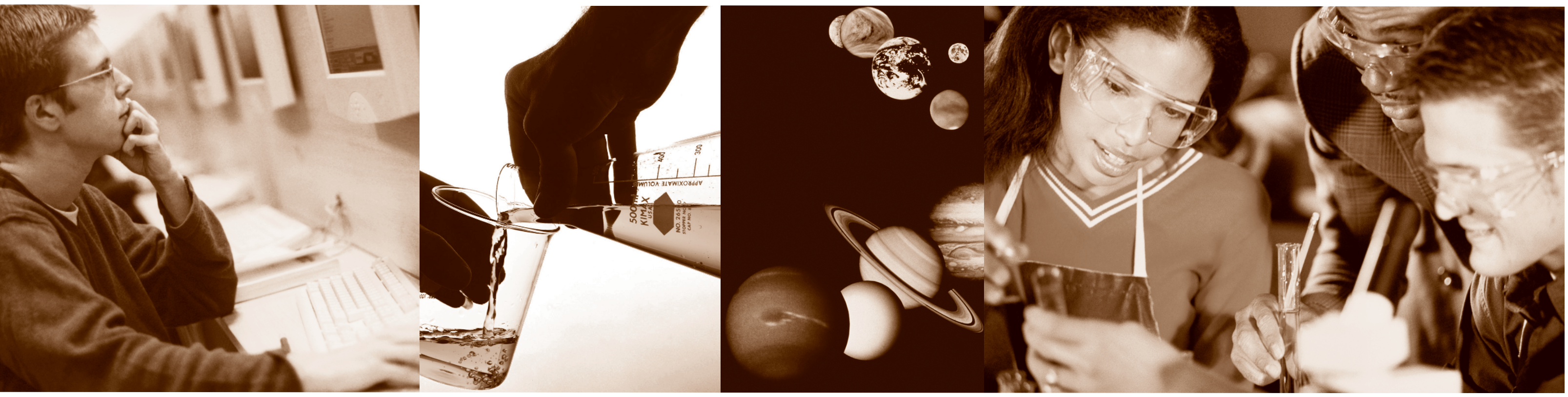
High School Content Expectations



SCIENCE

- **Earth Science**
- Biology
- Physics
- Chemistry

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MICHIGAN Department of Education
10/06

Michigan State Board of Education

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Welcome to Michigan's High School Science Content Standards and Expectations

Why Develop Content Standards and Expectations for High School?

To prepare Michigan's students with the knowledge and skills to succeed in the 21st Century, the State of Michigan has enacted a rigorous new set of statewide graduation requirements that are among the best in the nation. These requirements, called the Michigan Merit Curriculum, are the result of a collaborative effort between Governor Jennifer M. Granholm, the State Board of Education, and the State Legislature.

In preparation for the implementation of the new high school graduation requirements, the Michigan Department of Education's Office of School Improvement is leading the development of high school content expectations. An Academic Work Group of science experts chaired by nationally known scholars was commissioned to conduct a scholarly review and identify content standards and expectations. The Michigan Department of Education conducted an extensive field review of the expectations by high school, university, and business and industry representatives.

The Michigan High School Science Content Expectations (Science HSCE) establish what every student is expected to know and be able to do by the end of high school and define the expectations for high school science credit in Earth Science, Biology, Physics, and Chemistry.

An Overview

In developing these expectations, the Academic Work Group depended heavily on the *Science Framework for the 2009 National Assessment of Educational Progress* (National Assessment Governing Board, 2006). In particular, the group adapted the structure of the NAEP framework, including Content Statements and Performance Expectations. These expectations align closely with the NAEP framework, which is based on *Benchmarks for Science Literacy* (AAAS Project 2061, 1993) and the *National Science Education Standards* (National Research Council, 1996).

The Academic Work Group carefully analyzed other documents, including the Michigan Curriculum Framework Science Benchmarks (2000 revision), the Standards for Success report *Understanding University Success*, ACT's *College Readiness Standards*, College Board's *AP Biology, AP Physics, AP Chemistry,* and *AP Environmental Science Course Descriptions*, ACT's *On Course for Success*, South Regional Education Board's *Getting Ready for College-Preparatory/Honors Science: What Middle Grades Students Need to Know and Be Able to Do,* and standards documents from other states.

Earth Science	Biology	Physics	Chemistry
STANDARDS *(and number of content statements in each standard)*			
E1 Inquiry, Reflection, and Social Implications (2) E2 Earth Systems (4) E3 The Solid Earth (4) E4 The Fluid Earth (3) E5 Earth in Space and Time (4)	B1 Inquiry, Reflection, and Social Implications (2) B2 Organization and Development of Living Systems (6) B3 Interdependence of Living Systems and the Environment (5) B4 Genetics (4) B5 Evolution and Biodiversity (3)	P1 Inquiry, Reflection, and Social Implications (2) P2 Motion of Objects (3) P3 Forces and Motion (8) P4 Forms of Energy and Energy Transformations (12)	C1 Inquiry, Reflection, and Social Implications (2) C2 Forms of Energy (5) C3 Energy Transfer and Conservation (5) C4 Properties of Matter (10) C5 Changes in Matter (7)

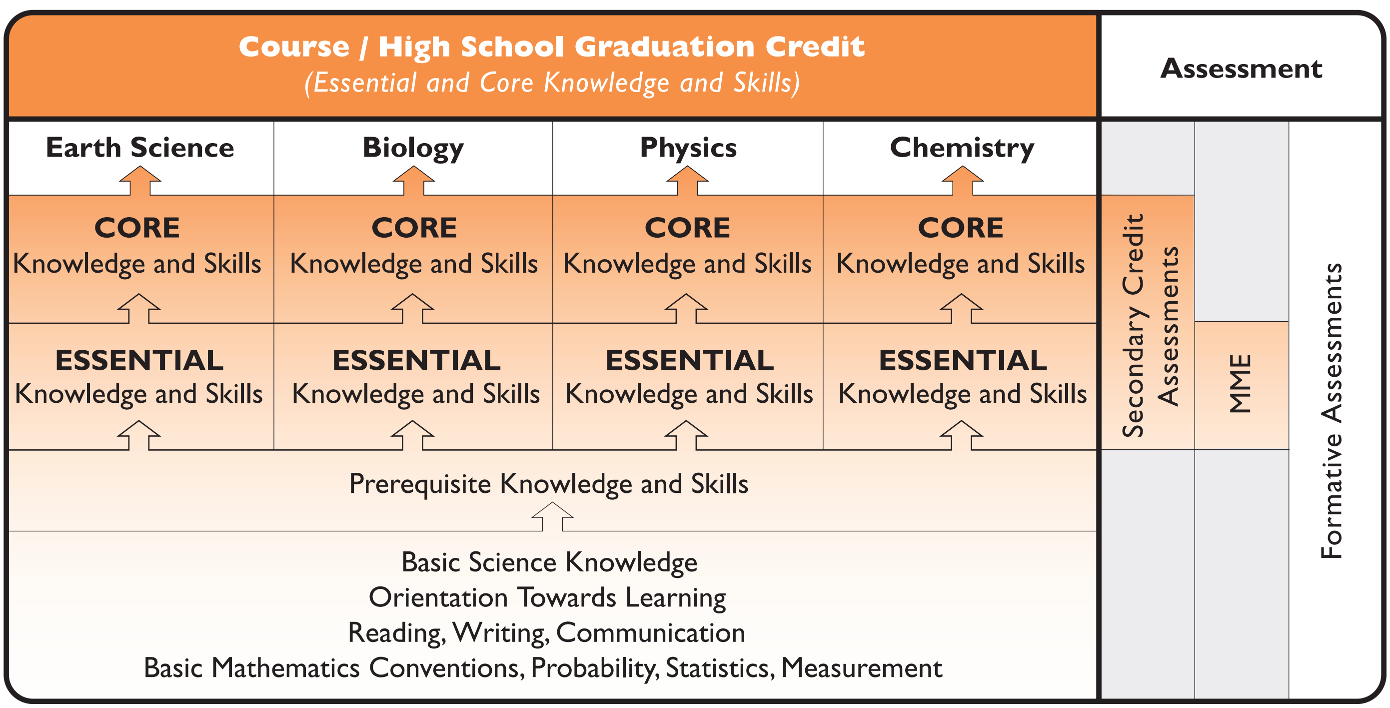
Useful and Connected Knowledge for All Students

This document defines expectations for Michigan High School graduates, organized by discipline: Earth Science, Biology, Physics, and Chemistry. It defines ***useful*** and ***connected knowledge*** at four levels:

- **Prerequisite knowledge**
  Useful and connected knowledge that all students should bring as a prerequisite to high school science classes. Prerequisite expectation codes include a "**p**" and an upper case letter (e.g., **E3.p1A**). Prerequisite content could be assessed through formative and/or large scale assessments.
- **Essential knowledge**
  Useful and connected knowledge for all high school graduates, regardless of what courses they take in high school. Essential expectation codes include an upper case letter (e.g., **E2.1A**). Essential content knowledge and performance expectations are required for graduation and are assessable on the Michigan Merit Exam (MME) and on future secondary assessments. Essential knowledge can also be assessed with formative assessments.
- **Core knowledge**
  Useful and connected knowledge for all high school graduates who have completed a discipline-specific course. In general core knowledge includes content and expectations that students need to be prepared for more advanced study in that discipline. Core content statement codes include an "x" and core expectation codes include a lower case letter (e.g., **B2.2x** Proteins; **B2.2f**) to indicate that they are NOT assessable on existing large-scale assessments (MME, NAEP), but will be assessed on future secondary credit assessments. Core knowledge can also be assessed with formative assessments.
- **Recommended knowledge**
  Useful and connected knowledge that is desirable as preparation for more advanced study in the discipline, but not required for graduation credit. Content and expectations labeled as recommended represent extensions of the core. Recommended content statement codes include an "**r**" and an "**x**"; recommended expectations include an "**r**" and a lower case letter (e.g., **P4.r9x Nature of Light**; **P4.r9a**). They will not be assessed on either the MME or secondary credit assessments.

Useful and connected knowledge is contrasted with ***procedural display***—learning to manipulate words and symbols without fully understanding their meaning. When expectations are excessive, procedural display is the kind of learning that takes place. Teachers and students "cover the content" instead of "uncovering" useful and connected knowledge.

Credit for high school Earth Science, Biology, Physics, and Chemistry will be defined as meeting both essential and core subject area content expectations. Credit requirements are outlined in separate Michigan Merit Curriculum Course/Credit Requirement documents.



Preparing Students for Successful Post-Secondary Engagement

Students who have useful and connected knowledge should be able to apply knowledge in new situations; to solve problems by generating new ideas; to make connections among what they read and hear in class, the world around them, and the future; and through their work, to develop leadership qualities while still in high school. In particular, high school graduates with useful and connected knowledge are able to engage in four key practices of science literacy.

Successful Post-Secondary Engagement

Practices of Science Literacy

Communicate accurately and effectively...

Identifying Science Principles

- Describe, measure, or classify observations.
- State or recognize correct science principles.
- Demonstrate relationships among closely related science principles.
- Demonstrate relationships among different representations of principles.

Using Science Principles

- Explain observations of phenomena.
- Predict observations of phenomena.
- Suggest examples of observations that illustrate a science principle.
- Propose, analyze, and evaluate alternative explanations or predictions.

Scientific Inquiry

- Generate new questions that can be investigated in the laboratory or field.
- Critique aspects of scientific investigations.
- Conduct scientific investigations using appropriate tools and techniques.
- Identify patterns in data: relate patterns to theoretical models.
- Describe a reason for a given conclusion using evidence from an investigation.
- Explain how scientific evidence supports or refutes claims or explanations of phenomena.
- Design and conduct a scientific investigation with a hypothesis, several controlled variables, and one manipulated variable. Gather data and organized the results in graphs, tables, and/or charts.

Reflection and Social Implications

- Critique whether questions can be answered through scientific investigations.
- Identify and critique arguments based on scientific evidence.
- Use appropriate scientific knowledge in social arguments, recognizing their limitations.
- Gather, synthesize, and evaluate information from multiple sources.
- Discuss scientific topics in groups, make presentations summarize what others have said, ask for clarification, take alternative perspectives, and defend a position.
- Evaluate the future career and occupational prospects of science fields.
- Explain why a claim or a conclusion is flawed.
- Critique solutions to problems, given criteria and scientific constraints.
- Identify scientific tradeoffs in design decisions and choose among alternative solutions.
- Apply science principles or scientific data to anticipate effects of technological design decisions.

State / National Landscape

- Expert perspective
- Education reform environment
- Research-based practices
- Work force requirements

State / Federal Expectations

- No Child Left Behind (NCLB)
- National Governors' Association (NGA)
- Legislation/Policy

Michigan High School Science Content Standards and Expectations

Earth Science

Biology

Physics

Chemistry

Models for District Alignment / Mapping

- District curriculum documents
- Documents from other districts/states
- Backmapping to standards and expectations

Other MI Documents / Programs

- State Standards – teaching and learning, content (all areas), assessment
- Grade Level Content Expectations
- State Assessments
- Career/Technical Education Department of Labor and Economic Growth

K-8 Educational Experience

Content Knowledge

- English Language Arts
- Mathematics
- Science
- Social Studies
- Other

Learning Processes

- Strategies & Skills
- Reasoning
- Analytical Thinking
- Constructing New Meaning
- Communication

This chart includes talking points for professional development.

Practices of Science Literacy

- **Identifying**
  Identifying performances generally have to do with stating models, theories, and patterns inside the triangle in Figure 1.
- **Using**
  Using performances generally have to do with the downward arrow in Figure 1—using scientific models and patterns to explain or describe specific observations.
- **Inquiry**
  Inquiry performances generally have to do with the upward arrow in Figure 1—finding and explaining patterns in data.
- **Reflection and Social Implications**
  Reflecting and Social Implications performances generally have to do with the figure as a whole (reflecting) or the downward arrow (technology as the application of models and theories to practical problems).

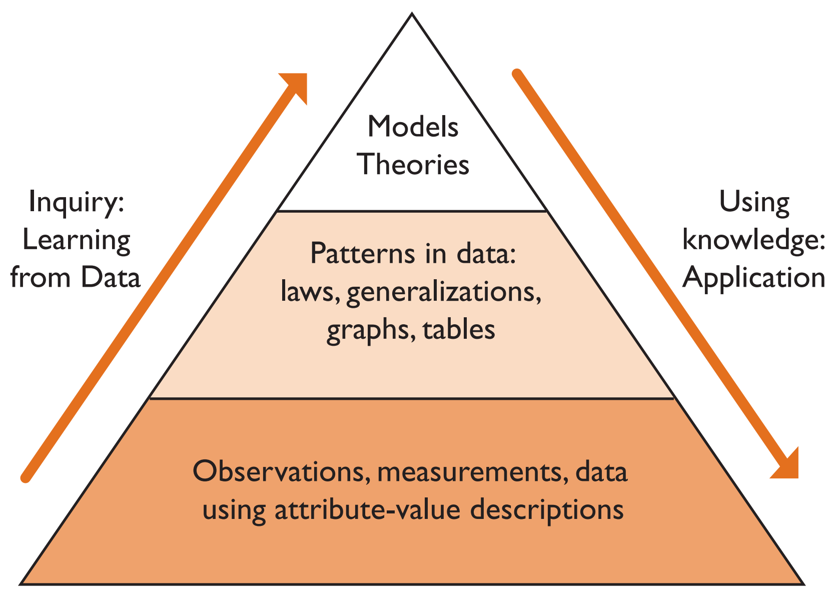


Figure 1: Knowledge and practices of model-based reasoning

Identifying Science Principles

This category focuses on students' abilities to recall, define, relate, and represent basic science principles. The content statements themselves are often closely related to one another conceptually. Moreover, the science principles included in the content statements can be represented in a variety of forms, such as words, pictures, graphs, tables, formulas, and diagrams (AAAS, 1993; NRC, 1996). Identifying practices include describing, measuring, or classifying observations; stating or recognizing principles included in the content statements; connecting closely related content statements; and relating different representations of science knowledge.

Identifying Science Principles comprises the following general types of practices:

- Describe, measure, or classify observations (e.g., describe the position and motion of objects, measure temperature, classify relationships between organisms as being predator/prey, parasite/host, producer/consumer).
- State or recognize correct science principles (e.g., mass is conserved when substances undergo changes of state; all organisms are composed of cells; the atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor).
- Demonstrate relationships among closely related science principles (e.g., statements of Newton's three laws of motion, energy transfer and the water cycle).
- Demonstrate relationships among different representations of principles (e.g., verbal, symbolic, diagrammatic) and data patterns (e.g., tables, equations, graphs).

Identifying Science Principles is integral to all of the other science practices.

Using Science Principles

Scientific knowledge is useful for making sense of the natural world. Both scientists and informed citizens can use patterns in observations and theoretical models to predict and explain observations that they make now or that they will make in the future.

Using Science Principles comprises the following general types of performance expectations:

- Explain observations of phenomena (using science principles from the content statements).
- Predict observations of phenomena (using science principles from the content statements, including quantitative predictions based on science principles that specify quantitative relationships among variables).
- Suggest examples of observations that illustrate a science principle (e.g., identify examples where the net force on an object is zero; provide examples of observations explained by the movement of tectonic plates; given partial DNA sequences of organisms, identify likely sequences of close relatives).
- Propose, analyze, and evaluate alternative explanations or predictions.

The first two categories—***Identifying Science Principles*** and ***Using Science Principles***—both require students to correctly state or recognize the science principles contained in the content statements. A difference between the categories is that Using Science Principles focuses on what makes science knowledge valuable—that is, its usefulness in making accurate predictions about phenomena and in explaining observations of the natural world in coherent ways (i.e., "knowing why"). Distinguishing between these two categories draws attention to differences in depth and richness of individuals' knowledge of the content statements. Assuming a continuum from "just knowing the facts" to "using science principles," there is considerable overlap at the boundaries. The line between the Identifying and Using categories is not distinct.

Scientific Inquiry

Scientifically literate graduates make observations about the natural world, identify patterns in data, and propose explanations to account for the patterns. Scientific inquiry involves the collection of relevant data, the use of logical reasoning, and the application of imagination in devising hypotheses to explain patterns in data. Scientific inquiry is a complex and time-intensive process that is iterative rather than linear. Habits of mind—curiosity, openness to new ideas, informed skepticism—are part of scientific inquiry. This includes the ability to read or listen critically to assertions in the media, deciding what evidence to pay attention to and what to dismiss, and distinguishing careful arguments from shoddy ones. Thus, Scientific Inquiry depends on the practices described above—Identifying Science Principles and Using Science Principles.

Scientific Inquiry comprises the following general types of performance expectations:

- Generate new questions that can be investigated in the laboratory or field.
- Evaluate the uncertainties or validity of scientific conclusions using an understanding of sources of measurement error, the challenges of controlling variables, accuracy of data analysis, logic of argument, logic of experimental design, and/or the dependence on underlying assumptions.
- Conduct scientific investigations using appropriate tools and techniques (e.g., selecting an instrument that measures the desired quantity—length, volume, weight, time interval, temperature—with the appropriate level of precision).
- Identify patterns in data and relate them to theoretical models.
- Describe a reason for a given conclusion using evidence from an investigation.
- Predict what would happen if the variables, methods, or timing of an investigation were changed.
- Based on empirical evidence, explain and critique the reasoning used to draw a scientific conclusion or explanation.
- Design and conduct a systematic scientific investigation that tests a hypothesis. Draw conclusions from data presented in charts or tables.
- Distinguish between scientific explanations that are regarded as current scientific consensus and the emerging questions that active researchers investigate.

Scientific inquiry is more complex than simply making, summarizing, and explaining observations, and it is more flexible than the rigid set of steps often referred to as the "scientific method." The *National Standards* makes it clear that inquiry goes beyond "science as a process" to include an understanding of the nature of science (p. 105).

It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, theoretical models, and the explanations proposed by other scientists. Evaluation includes reviewing the experimental procedures, examining the evidence, identifying faulty reasoning, pointing out statements that go beyond the evidence, and suggesting alternative explanations for the same observations (p. 171).

When students engage in Scientific Inquiry, they are drawing on their understanding about the nature of science, including the following ideas (see Benchmarks for Science Literacy):

- Arguments are flawed when fact and opinion are intermingled or the conclusions do not follow logically from the evidence given.
- A single example can never support the inference that something is always true, but sometimes a single example can support the inference that something is not always true.
- If more than one variable changes at the same time in an experiment, the outcome of the experiment may not be clearly attributable to any one of the variables.
- The way in which a sample is drawn affects how well it represents the population of interest. The larger the sample, the smaller the error in inference to the population. But, large samples do not necessarily guarantee representation, especially in the absence of random sampling.

Students can demonstrate their abilities to engage in Scientific Inquiry in two ways: students can *do* the practices specified above, and students can *critique examples* of scientific inquiry. In *doing*, practices can include analyzing data tables and deciding which conclusions are consistent with the data. Other practices involve hands-on performance and/or interactive computer tasks—for example, where students collect data and present their results or where students specify experimental conditions on computer simulations and observe the outcomes. As to *critiquing*, students can identify flaws in a poorly designed investigation or suggest changes in the design in order to produce more reliable data. Students should also be able to critique print or electronic media—for example, items may ask students to suggest alternative interpretations of data described in a newspaper article.

Scientific Reflection and Social Implications

Scientifically literate people recognize the strengths and limitations of scientific knowledge, which will provide the perspective they need to use the information to solve real-world problems. Students must learn to decide who and what sources of information they can trust. They need to learn to critique and justify their own ideas and the ideas of others. Since knowledge comes from many sources, students need to appreciate the historical origins of modern science and the multitude of connections between science and other disciplines. Students need to understand how science and technology support one another and the political, economic, and environmental consequences of scientific and technological progress. Finally, it is important that the ideas and contributions of men and women from all cultures be recognized as having played a significant role in scientific communities.

Scientific Reflection and Social Implications include the following general types of practices, all of which entail students using science knowledge to:

- Critique whether or not specific questions can be answered through scientific investigations.
- Identify and critique arguments about personal or societal issues based on scientific evidence.
- Develop an understanding of a scientific concept by accessing information from multiple sources. Evaluate the scientific accuracy and significance of the information.
- Evaluate scientific explanations in a peer review process or discussion format.
- Evaluate the future career and occupational prospects of science fields.
- Critique solutions to problems, given criteria and scientific constraints.
- Identify scientific tradeoffs in design decisions and choose among alternative solutions.
- Describe the distinctions between scientific theories, laws, hypotheses, and observations.
- Explain the progression of ideas and explanations that lead to science theories that are part of the current scientific consensus or core knowledge.
- Apply science principles or scientific data to anticipate effects of technological design decisions.
- Analyze how science and society interact from a historical, political, economic, or social perspective.

Organization of the Expectations

The Science Expectations are organized into Disciplines, Standards, Content Statements, and specific Performance Expectations.

Disciplines

Earth Science, Biology, Physics, and Chemistry

Organization of Each Standard

Each standard includes three parts:

- A standard statement that describes what students who have mastered that standard will be able to do.
- Content statements that describe Prerequisite, Essential, Core, and Recommended science content understanding for that standard.
- Performance expectations that describe Prerequisite, Essential, Core, and Recommended performances for that standard.

NOTE: Boundary statements that clarify the standards and set limits for expected performances, technical vocabulary, and additional discipline-specific inquiry and reflection expectations will be included in a companion document.

Standard Statement

The Standard Statement describes how students who meet that standard will engage in Identifying, Using, Inquiry, or Reflection for that topic.

Content Statements

Content statements describe the Prerequisite, Essential, Core, and Recommended *knowledge* associated with the standard.

1. ***Prerequisite science content*** that all students should bring as a prerequisite to high school science classes. Prerequisite content statement codes include a "**p**" and are organized by topic [e.g., **E3.p1 Landforms and Soils *(prerequisite)***].
2. ***Essential science content*** that all high school graduates should master. Essential content and expectations are organized by topic (e.g., **E2.1 Earth Systems Overview**).
3. ***Core science content*** that high school graduates need for more advanced study in the discipline and for some kinds of work. Core content and expectations are organized by topic (e.g., **B2.2x Proteins)**; "**x**" designates a core topic).
4. ***Recommended science content*** that is desirable as preparation for more advanced study in the discipline, but is not required for credit. Content and expectations labeled as recommended represent extensions of the core. Recommended content statement codes include an "**r**" and an "**x**"; expectations include an "**r**" and a lower case letter (e.g., **P4.r9x Nature of Light**; **P4.r9a**).

NOTE: Basic mathematics and English language arts skills necessary for meeting the high school science content expectations will be included in a companion document.

Performance Expectations

Performance expectations are derived from the intersection of content statements and practices—if the content statements from the Earth Sciences, Biology, Physics, and Chemistry are the columns of a table and the practices (Identifying Science Principles, Using Science Principles, Using Scientific Inquiry, Reflection and Social Implications) are the rows, the cells of the table are inhabited by performance expectations.

Performance expectations are written with particular verbs indicating the desired performance expected of the student. The action verbs associated with each practice are contextualized to generate performance expectations. For example, when the "conduct scientific investigations" is crossed with a states-of-matter content statement, this can generate a performance expectation that employs a different action verb, "heats as a way to evaporate liquids."

Michigan High School Science

EARTH SCIENCE

Prerequisite, Essential, Core, and Recommended Content Statements and Expectations

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EARTH SCIENCE (E)

In recent years, the study of Earth has undergone profound changes. It has expanded from surface geology and the recovery of economic resources toward global change and Earth systems. Concurrently, research methods have changed from solely using human observations and mapping, to using remote sensing and computer modeling. The advent of technology has made it possible to conduct more integrated and interdisciplinary research to view the Earth as a single dynamic entity composed of four interacting systems.

The Earth system is usually subdivided into the geosphere (solid Earth), the hydrosphere (the liquid part of the planet), the atmosphere (the gaseous part of the planet), and the biosphere (the living part of the planet). These four parts do not exist in isolation, but are interconnected by complex cycles. Alterations to one part of the Earth system result in effects on another part of the system. The study of the individual components and their interactions are necessary to completely understand the complex dynamics of our planet.

There has also been a shift in goals, as advances in theory have made it possible to more accurately predict changes (especially in weather and climate), to provide life-saving warnings of floods, hurricanes, and volcanic eruptions, and to understand how human activities influence air and water quality, ecosystems, and climate across the globe. We are also better prepared to understand the processes that occur within and between each of the Earth systems.

Recent research in the Earth sciences has focused on:

1. climate variability and change
2. impact of elements and compounds on ecosystems
3. water and energy cycles
4. atmospheric processes
5. earth surface and internal processes.

National education standards have moved to mirror these foci, requiring that students explore the methods and tools for studying Earth systems. In addition, public awareness and education is critical in mitigating the effects of natural hazards as economic and population growth expand in areas most susceptible to the effects of nature (e.g., Florida, Texas, California). Events such as hurricanes and tsunamis demonstrate the significant impacts of the Earth on society. Some of the decisions students will need to consider include, where to live, where to store waste, and where to develop.

Many topics and questions of Earth science lend themselves well to the possibility of offering direct and authentic empirical experience to K-12 students. For example, all students live in a watershed, experience severe weather, and observe landforms, all of which can be observed and researched by students.

However, unlike many other disciplines, direct experimentation and observation are difficult in many aspects of the Earth sciences. Scientists often must depend on the formulation of models both to describe and to determine the implications of various factors. Many aspects of the Earth sciences occur over very long time frames ("deep time"), as well as deep in the Earth or far off in space, that need to be studied more like a murder mystery with inferences from indirect data; such concepts are often difficult for students to comprehend.

The tools available to both scientists and students for learning about Earth and space have changed as well. Communication and visualization tools, such as the internet and data bases, have made it possible for Earth science students to have direct access to the raw data and models used by scientists and to pursue real world questions and inquiry. Other web-based programs allow students to view and process satellite images of Earth, to direct a camera on board the Space Shuttle, and to access professional telescopes around the world to carry out science projects.

The Earth system, however, is generally too complex for students to view as whole, thus it is best to study each of the components separately. It is imperative, however, that students inquire about and understand the interconnections between Earth systems and distinguish between systems at "micro" and "macro" levels. In light of this, many content statements in this document cross standard boundaries and are interconnected.

The Earth science standards focus on:

1. the nature and practice of scientific inquiry
2. the Earth system and the movement of elements, compounds, and energy through it
3. the solid Earth and its hazards
4. the fluid Earth, and its hazards
5. the history of the Earth and the universe

The standards begin with a section on the nature and practice of science. This is followed by an overview of Earth systems and cycles and the movement of elements, compounds, and energy within and between the four component systems. This is followed by an examination of the major components of the Earth system that are covered in Earth Science courses, focusing on the solid Earth (geosphere) and fluid Earth (hydrology, oceans, climate, and weather). The final standard covers the position of the Earth in the universe and its evolution over time.

The interdisciplinary nature of the Earth sciences makes it difficult to rigidly separate and sequence subject matter. Many topics can fit equally well in many different places. This document represents one possible organizational structure.

Earth Science Content Statement Outline

STANDARD E1 Inquiry, Reflection, and Social Implications

- E1.1 Scientific Inquiry
- E1.2 Scientific Reflection and Social Implications

STANDARD E2 Earth Systems

- E2.1 Earth Systems Overview
- E2.2 Energy in Earth Systems
- E2.3 Biogeochemical Cycles
- E2.4 Resources and Human Impacts on Earth Systems

STANDARD E3 Solid Earth

- E3.p1 Landforms and Soils *(prerequisite)*
- E3.p2 Rocks and Minerals *(prerequisite)*
- E3.p3 Basic Plate Tectonics *(prerequisite)*
- E3.1 Advanced Rock Cycle
- E3.2 Interior of the Earth
- E3.3 Plate Tectonics Theory
- E3.4 Earthquakes and Volcanoes

STANDARD E4 Fluid Earth

- E4.p1 Water Cycle *(prerequisite)*
- E4.p2 Weather and the Atmosphere *(prerequisite)*
- E4.p3 Glaciers *(prerequisite)*
- E4.1 Hydrogeology
- E4.2 Oceans and Climate
- E4.3 Severe Weather

STANDARD E5 The Earth in Space and Time

- E5.p1 Sky Observations *(prerequisite)*
- E5.1 The Earth in Space
- E5.2 The Sun
- E5.2x Stellar Evolution
- E5.3 Earth History and Geologic Time
- E5.3x Geologic Dating
- E5.4 Climate Change

STANDARD E1: INQUIRY, REFLECTION, AND SOCIAL IMPLICATIONS

Students will understand the nature of science and demonstrate an ability to practice scientific reasoning by applying it to the design, execution, and evaluation of scientific investigations. Students will demonstrate their understanding that scientific knowledge is gathered through various forms of direct and indirect observations and the testing of this information by methods including, but not limited to, experimentation. They will be able to distinguish between types of scientific knowledge (e.g., hypotheses, laws, theories) and become aware of areas of active research in contrast to conclusions that are part of established scientific consensus. They will use their scientific knowledge to assess the costs, risks, and benefits of technological systems as they make personal choices and participate in public policy decisions. These insights will help them analyze the role science plays in society, technology, and potential career opportunities.

E1.1 Scientific Inquiry

Science is a way of understanding nature. Scientific research may begin by generating new scientific questions that can be answered through replicable scientific investigations that are logically developed and conducted systematically. Scientific conclusions and explanations result from careful analysis of empirical evidence and the use of logical reasoning. Some questions in science are addressed through indirect rather than direct observation, evaluating the consistency of new evidence with results predicted by models of natural processes. Results from investigations are communicated in reports that are scrutinized through a peer review process.

E1.1A Generate new questions that can be investigated in the laboratory or field.

E1.1B Evaluate the uncertainties or validity of scientific conclusions using an understanding of sources of measurement error, the challenges of controlling variables, accuracy of data analysis, logic of argument, logic of experimental design, and/or the dependence on underlying assumptions.

E1.1C Conduct scientific investigations using appropriate tools and techniques (e.g., selecting an instrument that measures the desired quantity—length, volume, weight, time interval, temperature—with the appropriate level of precision).

E1.1D Identify patterns in data and relate them to theoretical models.

E1.1E Describe a reason for a given conclusion using evidence from an investigation.

E1.1f Predict what would happen if the variables, methods, or timing of an investigation were changed.

E1.1g Based on empirical evidence, explain and critique the reasoning used to draw a scientific conclusion or explanation.

E1.1h Design and conduct a systematic scientific investigation that tests a hypothesis. Draw conclusions from data presented in charts or tables.

E1.1i Distinguish between scientific explanations that are regarded as current scientific consensus and the emerging questions that active researchers investigate.

E1.2 Scientific Reflection and Social Implications

The integrity of the scientific process depends on scientists and citizens understanding and respecting the "Nature of Science." Openness to new ideas, skepticism, and honesty are attributes required for good scientific practice. Scientists must use logical reasoning during investigation design, analysis, conclusion, and communication. Science can produce critical insights on societal problems from a personal and local scale to a global scale. Science both aids in the development of technology and provides tools for assessing the costs, risks, and benefits of technological systems. Scientific conclusions and arguments play a role in personal choice and public policy decisions. New technology and scientific discoveries have had a major influence in shaping human history. Science and technology continue to offer diverse and significant career opportunities.

E1.2A Critique whether or not specific questions can be answered through scientific investigations.

E1.2B Identify and critique arguments about personal or societal issues based on scientific evidence.

E1.2C Develop an understanding of a scientific concept by accessing information from multiple sources. Evaluate the scientific accuracy and significance of the information.

E1.2D Evaluate scientific explanations in a peer review process or discussion format.

E1.2E Evaluate the future career and occupational prospects of science fields.

E1.2f Critique solutions to problems, given criteria and scientific constraints.

E1.2g Identify scientific tradeoffs in design decisions and choose among alternative solutions.

E1.2h Describe the distinctions between scientific theories, laws, hypotheses, and observations.

E1.2i Explain the progression of ideas and explanations that lead to science theories that are part of the current scientific consensus or core knowledge.

E1.2j Apply science principles or scientific data to anticipate effects of technological design decisions.

E1.2k Analyze how science and society interact from a historical, political, economic, or social perspective.

STANDARD E2: EARTH SYSTEMS

Students describe the interactions within and between Earth systems. Students will explain how both fluids (water cycle) and solids (rock cycle) move within Earth systems and how these movements form and change their environment. They will describe the relationship between physical process and human activities and use this understanding to demonstrate an ability to make wise decisions about land use.

E2.1 Earth Systems Overview

The Earth is a system consisting of four major interacting components: geosphere (crust, mantle, and core), atmosphere (air), hydrosphere (water), and biosphere (the living part of Earth). Physical, chemical, and biological processes act within and among the four components on a wide range of time scales to continuously change Earth's crust, oceans, atmosphere, and living organisms. Earth elements move within and between the lithosphere, atmosphere, hydrosphere, and biosphere as part of geochemical cycles.

E2.1A Explain why the Earth is essentially a closed system in terms of matter.

E2.1B Analyze the interactions between the major systems (geosphere, atmosphere, hydrosphere, biosphere) that make up the Earth.

E2.1C Explain, using specific examples, how a change in one system affects other Earth systems.

E2.2 Energy in Earth Systems

Energy in Earth systems can exist in a number of forms (e.g., thermal energy as heat in the Earth, chemical energy stored as fossil fuels, mechanical energy as delivered by tides) and can be transformed from one state to another and move from one reservoir to another. Movement of matter and its component elements, through and between Earth's systems, is driven by Earth's internal (radioactive decay and gravity) and external (Sun as primary) sources of energy. Thermal energy is transferred by radiation, convection, and conduction. Fossil fuels are derived from plants and animals of the past, are nonrenewable, and, therefore, are limited in availability. All sources of energy for human consumption (e.g., solar, wind, nuclear, ethanol, hydrogen, geothermal, hydroelectric) have advantages and disadvantages.

E2.2A Describe the Earth's principal sources of internal and external energy (e.g., radioactive decay, gravity, solar energy).

E2.2B Identify differences in the origin and use of renewable (e.g., solar, wind, water, biomass) and nonrenewable (e.g., fossil fuels, nuclear [U-235]) sources of energy.

E2.2C Describe natural processes in which heat transfer in the Earth occurs by conduction, convection, and radiation.

E2.2D Identify the main sources of energy to the climate system.

E2.2e Explain how energy changes form through Earth systems.

E2.2f Explain how elements exist in different compounds and states as they move from one reservoir to another.

E2.3 Biogeochemical Cycles

The Earth is a system containing essentially a fixed amount of each stable chemical atom or element. Most elements can exist in several different states and chemical forms; they move within and between the geosphere, atmosphere, hydrosphere, and biosphere as part of the Earth system. The movements can be slow or rapid. Elements and compounds have significant impacts on the biosphere and have important impacts on human health.

E2.3A Explain how carbon exists in different forms such as limestone (rock), carbon dioxide (gas), carbonic acid (water), and animals (life) within Earth systems and how those forms can be beneficial or harmful to humans.

E2.3b Explain why small amounts of some chemical forms may be beneficial for life but are poisonous in large quantities (e.g., dead zone in the Gulf of Mexico, Lake Nyos in Africa, fluoride in drinking water).

E2.3c Explain how the nitrogen cycle is part of the Earth system.

E2.3d Explain how carbon moves through the Earth system (including the geosphere) and how it may benefit (e.g., improve soils for agriculture) or harm (e.g., act as a pollutant) society.

E2.4 Resources and Human Impacts on Earth Systems

The Earth provides resources (including minerals) that are used to sustain human affairs. The supply of nonrenewable natural resources is limited and their extraction and use can release elements and compounds into Earth systems. They affect air and water quality, ecosystems, landscapes, and may have effects on long-term climate. Plans for land use and long-term development must include an understanding of the interactions between Earth systems and human activities.

E2.4A Describe renewable and nonrenewable sources of energy for human consumption (electricity, fuels), compare their effects on the environment, and include overall costs and benefits.

E2.4B Explain how the impact of human activities on the environment (e.g., deforestation, air pollution, coral reef destruction) can be understood through the analysis of interactions between the four Earth systems.

E2.4c Explain ozone depletion in the stratosphere and methods to slow human activities to reduce ozone depletion.

E2.4d Describe the life cycle of a product, including the resources, production, packaging, transportation, disposal, and pollution.

STANDARD E3: THE SOLID EARTH

Students explain how scientists study and model the interior of the Earth and its dynamic nature. They use the theory of plate tectonics, the unifying theory of geology, to explain a wide variety of Earth features and processes and how hazards resulting from these processes impact society.

E3.p1 Landforms and Soils *(prerequisite)*

Landforms are the result of a combination of constructive and destructive forces. Constructive forces include crustal deformation, volcanic eruptions, and deposition of sediments transported in rivers, streams, and lakes through watersheds. Destructive forces include weathering and erosion. The weathering of rocks and decomposed organic matter result in the formation of soils. *(prerequisite)*

E3.p1A Explain the origin of Michigan landforms. Describe and identify surface features using maps and satellite images. *(prerequisite)*

E3.p1B Explain how physical and chemical weathering leads to erosion and the formation of soils and sediments. *(prerequisite)*

E3.p1C Describe how coastal features are formed by wave erosion and deposition. *(prerequisite)*

E3.p2 Rocks and Minerals *(prerequisite)*

Igneous, metamorphic, and sedimentary rocks are constantly forming and changing through various processes. As they do so, elements move through the geosphere. In addition to other geologic features, rocks and minerals are indicators of geologic and environmental conditions that existed in the past. *(prerequisite)*

E3.p2A Identify common rock-forming minerals (quartz, feldspar, biotite, calcite, hornblende). *(prerequisite)*

E3.p2B Identify common igneous (granite, basalt, andesite, obsidian, pumice), metamorphic (schist, gneiss, marble, slate, quartzite), and sedimentary (sandstone, limestone, shale, conglomerate) rocks and describe the processes that change one kind of rock to another. *(prerequisite)*

E3.p3 Basic Plate Tectonics *(prerequisite)*

Early evidence for the movement of continents was based on the similarities of coastlines, geology, faunal distributions, and paleoclimatelogical data across the Atlantic and Indian Oceans. In the 1960s, additional evidence from marine geophysical surveys, seismology, volcanology, and paleomagnetism resulted in the development of the theory of plate tectonics. *(prerequisite)*

E3.p3A Describe geologic, paleontologic, and paleoclimatalogic evidence that indicates Africa and South America were once part of a single continent.

E3.p3B Describe the three types of plate boundaries (divergent, convergent, and transform) and geographic features associated with them (e.g., continental rifts and mid-ocean ridges, volcanic and island arcs, deep-sea trenches, transform faults).

E3.p3C Describe the three major types of volcanoes (shield volcano, stratovolcano, and cinder cones) and their relationship to the Ring of Fire.

E3.1 Advanced Rock Cycle

Igneous, metamorphic, and sedimentary rocks are indicators of geologic and environmental conditions and processes that existed in the past. These include cooling and crystallization, weathering and erosion, sedimentation and lithification, and metamorphism. In some way, all of these processes are influenced by plate tectonics, and some are influenced by climate.

E3.1A Discriminate between igneous, metamorphic, and sedimentary rocks and describe the processes that change one kind of rock into another.

E3.1B Explain the relationship between the rock cycle and plate tectonics theory in regard to the origins of igneous, sedimentary, and metamorphic rocks.

E3.1c Explain how the size and shape of grains in a sedimentary rock indicate the environment of formation (including climate) and deposition.

E3.1d Explain how the crystal sizes of igneous rocks indicate the rate of cooling and whether the rock is extrusive or intrusive.

E3.1e Explain how the texture (foliated, nonfoliated) of metamorphic rock can indicate whether it has experienced regional or contact metamorphism.

E3.2 Interior of the Earth

The Earth can also be subdivided into concentric layers based on their physical characteristics: (lithosphere, asthenosphere, lower mantle, outer core, and inner core). The crust and upper mantle compose the rigid lithosphere (plates) that moves over a "softer" asthenosphere (part of the upper mantle). The magnetic field of the Earth is generated in the outer core. The interior of the Earth cannot be directly sampled and must be modeled using data from seismology.

E3.2A Describe the interior of the Earth (in terms of crust, mantle, and inner and outer cores) and where the magnetic field of the Earth is generated.

E3.2B Explain how scientists infer that the Earth has interior layers with discernable properties using patterns of primary (*P*) and secondary (*S*) seismic wave arrivals.

E3.2C Describe the differences between oceanic and continental crust (including density, age, composition).

E3.2d Explain the uncertainties associated with models of the interior of the Earth and how these models are validated.

E3.3 Plate Tectonics Theory

The Earth's crust and upper mantle make up the lithosphere, which is broken into large mobile pieces called tectonic plates. The plates move at velocities in units of centimeters per year as measured using the global positioning system (GPS). Motion histories are determined with calculations that relate rate, time, and distance of offset geologic features. Oceanic plates are created at mid-ocean ridges by magmatic activity and cooled until they sink back into the Earth at subduction zones. At some localities, plates slide by each other. Mountain belts are formed both by continental collision and as a result of subduction. The outward flow of heat from Earth's interior provides the driving energy for plate tectonics.

E3.3A Explain how plate tectonics accounts for the features and processes (sea floor spreading, mid-ocean ridges, subduction zones, earthquakes and volcanoes, mountain ranges) that occur on or near the Earth's surface.

E3.3B Explain why tectonic plates move using the concept of heat flowing through mantle convection, coupled with the cooling and sinking of aging ocean plates that result from their increased density.

E3.3C Describe the motion history of geologic features (e.g., plates, Hawaii) using equations relating rate, time, and distance.

E3.3d Distinguish plate boundaries by the pattern of depth and magnitude of earthquakes.

E3.r3e Predict the temperature distribution in the lithosphere as a function of distance from the mid-ocean ridge and how it relates to ocean depth. *(recommended)*

E3.r3f Describe how the direction and rate of movement for the North American plate has affected the local climate over the last 600 million years. *(recommended)*

E3.4 Earthquakes and Volcanoes

Plate motions result in potentially catastrophic events (earthquakes, volcanoes, tsunamis, mass wasting) that affect humanity. The intensity of volcanic eruptions is controlled by the chemistry and properties of the magma. Earthquakes are the result of abrupt movements of the Earth. They generate energy in the form of body and surface waves.

E3.4A Use the distribution of earthquakes and volcanoes to locate and determine the types of plate boundaries.

E3.4B Describe how the sizes of earthquakes and volcanoes are measured or characterized.

E3.4C Describe the effects of earthquakes and volcanic eruptions on humans.

E3.4d Explain how the chemical composition of magmas relates to plate tectonics and affects the geometry, structure, and explosivity of volcanoes.

E3.4e Explain how volcanoes change the atmosphere, hydrosphere, and other Earth systems.

E3.4f Explain why fences are offset after an earthquake, using the elastic rebound theory.

STANDARD E4: THE FLUID EARTH

Students explain how the ocean and atmosphere move and transfer energy around the planet. They also explain how these movements affect climate and weather and how severe weather impacts society. Students explain how long term climatic changes (glaciers) have shaped the Michigan landscape. They also explain features and processes related to surface and ground-water and describe the sustainability of systems in terms of water quality and quantity.

E4.p1 Water Cycle *(prerequisite)*

Water circulates through the crust and atmosphere and in oceans, rivers, glaciers, and ice caps and connects all of the Earth systems. Groundwater is a significant reservoir and source of freshwater on Earth. The recharge and movement of groundwater depends on porosity, permeability, and the shape of the water table. The movement of groundwater occurs over a long period time. Groundwater and surface water are often interconnected. *(prerequisite)*

E4.p1A Describe that the water cycle includes evaporation, transpiration, condensation, precipitation, infiltration, surface runoff, groundwater, and absorption. *(prerequisite)*

E4.p1B Analyze the flow of water between the elements of a watershed, including surface features (lakes, streams, rivers, wetlands) and groundwater. *(prerequisite)*

E4.p1C Describe the river and stream types, features, and process including cycles of flooding, erosion, and deposition as they occur naturally and as they are impacted by land use decisions. *(prerequisite)*

E4.p1D Explain the types, process, and beneficial functions of wetlands.

E4.p2 Weather and the Atmosphere *(prerequisite)*

The atmosphere is divided into layers defined by temperature. Clouds are indicators of weather. *(prerequisite)*

E4.p2A Describe the composition and layers of the atmosphere. *(prerequisite)*

E4.p2B Describe the difference between weather and climate. *(prerequisite)*

E4.p2C Explain the differences between fog and dew formation and cloud formation. *(prerequisite)*

E4.p2D Describe relative humidity in terms of the moisture content of the air and the moisture capacity of the air and how these depend on the temperature. *(prerequisite)*

E4.p2E Describe conditions associated with frontal boundaries (cold, warm, stationary, and occluded). *(prerequisite)*

E4.p2F Describe the characteristics and movement across North America of the major air masses and the jet stream. *(prerequisite)*

E4.p2G Interpret a weather map and describe present weather conditions and predict changes in weather over 24 hours. *(prerequisite)*

E4.p2H Explain the primary causes of seasons. *(prerequisite)*

E4.p2I Identify major global wind belts (trade winds, prevailing westerlies, and polar easterlies) and that their vertical components control the global distribution of rainforests and deserts. *(prerequisite)*

E4.p3 Glaciers *(prerequisite)*

Glaciers are large bodies of ice that move under the influence of gravity. They form part of both the rock and water cycles. Glaciers and ice sheets have shaped the landscape of the Great Lakes region. Areas that have been occupied by ice sheets are depressed. When the ice sheet is removed, the region rebounds (see also climate change). *(prerequisite)*

E4.p3A Describe how glaciers have affected the Michigan landscape and how the resulting landforms impact our state economy. *(prerequisite)*

E4.p3B Explain what happens to the lithosphere when an ice sheet is removed. *(prerequisite)*

E4.p3C Explain the formation of the Great Lakes. *(prerequisite)*

E4.1 Hydrogeology

Fresh water moves over time between the atmosphere, hydrosphere (surface water, wetlands, rivers, and glaciers), and geosphere (groundwater). Water resources are both critical to and greatly impacted by humans. Changes in water systems will impact quality, quantity, and movement of water. Natural surface water processes shape the landscape everywhere and are affected by human land use decisions.

E4.1A Compare and contrast surface water systems (lakes, rivers, streams, wetlands) and groundwater in regard to their relative sizes as Earth's freshwater reservoirs and the dynamics of water movement (inputs and outputs, residence times, sustainability).

E4.1B Explain the features and processes of groundwater systems and how the sustainability of North American aquifers has changed in recent history (e.g., the past 100 years) qualitatively using the concepts of recharge, residence time, inputs, and outputs.

E4.1C Explain how water quality in both groundwater and surface systems is impacted by land use decisions.

E4.2 Oceans and Climate

Energy from the sun and the rotation of the Earth control global atmospheric circulation. Oceans redistribute matter and energy around the Earth through currents, waves, and interaction with other Earth systems. Ocean currents are controlled by prevailing winds, changes in water density, ocean topography, and the shape and location of landmasses. Oceans and large lakes (e.g., Great Lakes) have a major effect on climate and weather because they are a source of moisture and a large reservoir of heat. Interactions between oceanic circulation and the atmosphere can affect regional climates throughout the world.

E4.2A Describe the major causes for the ocean's surface and deep water currents, including the prevailing winds, the Coriolis effect, unequal heating of the earth, changes in water temperature and salinity in high latitudes, and basin shape.

E4.2B Explain how interactions between the oceans and the atmosphere influence global and regional climate. Include the major concepts of heat transfer by ocean currents, thermohaline circulation, boundary currents, evaporation, precipitation, climatic zones, and the ocean as a major CO_2 reservoir.

E4.2c Explain the dynamics (including ocean-atmosphere interactions) of the El Niño-Southern Oscillation (ENSO) and its effect on continental climates.

E4.2d Identify factors affecting seawater density and salinity and describe how density affects oceanic layering and currents.

E4.2e Explain the differences between maritime and continental climates with regard to oceanic currents.

E4.2f Explain how the Coriolis effect controls oceanic circulation.

E4.r2g Explain how El Niño affects economies (e.g., in South America). *(recommended)*

E4.3 Severe Weather

Tornadoes, hurricanes, blizzards, and thunderstorms are severe weather phenomena that impact society and ecosystems. Hazards include downbursts (wind shear), strong winds, hail, lightning, heavy rain, and flooding. The movement of air in the atmosphere is due to differences in air density resulting from variations in temperature. Many weather conditions can be explained by fronts that occur when air masses meet.

E4.3A Describe the various conditions of formation associated with severe weather (thunderstorms, tornadoes, hurricanes, floods, waves, and drought).

E4.3B Describe the damage resulting from, and the social impact of thunderstorms, tornadoes, hurricanes, and floods.

E4.3C Describe severe weather and flood safety and mitigation.

E4.3D Describe the seasonal variations in severe weather.

E4.3E Describe conditions associated with frontal boundaries that result in severe weather (thunderstorms, tornadoes, and hurricanes).

E4.3F Describe how mountains, frontal wedging (including dry lines), convection, and convergence form clouds and precipitation.

E4.3g Explain the process of adiabatic cooling and adiabatic temperature changes to the formation of clouds.

STANDARD E5: THE EARTH IN SPACE AND TIME

Students explain theories about how the Earth and universe formed and evolved over a long period of time. Students predict how human activities may influence the climate of the future.

E5.p1 Sky Observations *(prerequisite)*

Common sky observations (such as lunar phases) can be explained by the motion of solar system objects in regular and predictable patterns. Our galaxy, observable as the Milky Way, is composed of billions of stars, some of which have planetary systems. Seasons are a result of the tilt of the rotation axis of the Earth. The motions of the moon and sun affect the phases of the moon and ocean tides. *(prerequisite)*

E5.p1A Describe the motions of various celestial bodies and some effects of those motions. *(prerequisite)*

E5.p1B Explain the primary cause of seasons. *(prerequisite)*

E5.p1C Explain how a light year can be used as a distance unit. *(prerequisite)*

E5.p1D Describe the position and motion of our solar system in our galaxy. *(prerequisite)*

E5.1 The Earth in Space

Scientific evidence indicates the universe is orderly in structure, finite, and contains all matter and energy. Information from the entire light spectrum tells us about the composition and motion of objects in the universe. Early in the history of the universe, matter clumped together by gravitational attraction to form stars and galaxies. According to the Big Bang theory, the universe has been continually expanding at an increasing rate since its formation about 13.7 billion years ago.

E5.1A Describe the position and motion of our solar system in our galaxy and the overall scale, structure, and age of the universe.

E5.1b Describe how the Big Bang theory accounts for the formation of the universe.

E5.1c Explain how observations of the cosmic microwave background have helped determine the age of the universe.

E5.1d Differentiate between the cosmological and Doppler red shift.

E5.2 The Sun

Stars, including the Sun, transform matter into energy in nuclear reactions. When hydrogen nuclei fuse to form helium, a small amount of matter is converted to energy. Solar energy is responsible for life processes and weather as well as phenomena on Earth. These and other processes in stars have led to the formation of all the other chemical elements.

E5.2A Identify patterns in solar activities (sunspot cycle, solar flares, solar wind).

E5.2B Relate events on the Sun to phenomena such as auroras, disruption of radio and satellite communications, and power grid disturbances.

E5.2C Describe how nuclear fusion produces energy in the Sun.

E5.2D Describe how nuclear fusion and other processes in stars have led to the formation of all the other chemical elements.

E5.2x Stellar Evolution

Stars, including the Sun, transform matter into energy in nuclear reactions. When hydrogen nuclei fuse to form helium, a small amount of matter is converted to energy. These and other processes in stars have led to the formation of all the other chemical elements. There is a wide range of stellar objects of different sizes and temperatures. Stars have varying life histories based on these parameters.

E5.2e Explain how the Hertzsprung-Russell (H-R) diagram can be used to deduce other parameters (distance).

E5.2f Explain how you can infer the temperature, life span, and mass of a star from its color. Use the H-R diagram to explain the life cycles of stars.

E5.2g Explain how the balance between fusion and gravity controls the evolution of a star (equilibrium).

E5.2h Compare the evolution paths of low-, moderate-, and high-mass stars using the H-R diagram.

E5.3 Earth History and Geologic Time

The solar system formed from a nebular cloud of dust and gas 4.6 Ga (billion years ago). The Earth has changed through time and has been affected by both catastrophic (e.g., earthquakes, meteorite impacts, volcanoes) and gradual geologic events (e.g., plate movements, mountain building) as well as the effects of biological evolution (formation of an oxygen atmosphere). Geologic time can be determined through both relative and absolute dating.

E5.3A Explain how the solar system formed from a nebula of dust and gas in a spiral arm of the Milky Way Galaxy about 4.6 Ga (billion years ago).

E5.3B Describe the process of radioactive decay and explain how radioactive elements are used to date the rocks that contain them.

E5.3C Relate major events in the history of the Earth to the geologic time scale, including formation of the Earth, formation of an oxygen atmosphere, rise of life, Cretaceous-Tertiary (K-T) and Permian extinctions, and Pleistocene ice age.

E5.3D Describe how index fossils can be used to determine time sequence.

E5.3x Geologic Dating

Early methods of determining geologic time, such as the use of index fossils and stratigraphic principles, allowed for the relative dating of geological events. However, absolute dating was impossible until the discovery that certain radioactive isotopes in rocks have known decay rates, making it possible to determine how many years ago a given mineral or rock formed. Different kinds of radiometric dating techniques exist. Technique selection depends on the composition of the material to be dated, the age of the material, and the type of geologic event that affected the material.

E5.3e Determine the approximate age of a sample, when given the half-life of a radioactive substance (in graph or tabular form) along with the ratio of daughter to parent substances present in the sample.

E5.3f Explain why C-14 can be used to date a 40,000 year old tree, but U-Pb cannot.

E5.3g Identify a sequence of geologic events using relative-age dating principles.

E5.4 Climate Change

Atmospheric gases trap solar energy that has been reradiated from the Earth's surface (the greenhouse effect). The Earth's climate has changed both gradually and catastrophically over geological and historical time frames due to complex interactions between many natural variables and events. The concentration of greenhouse gases (especially carbon dioxide) has increased due to human industrialization, which has contributed to a rise in average global atmospheric temperatures and changes in the biosphere, atmosphere, and hydrosphere. Climates of the past are researched, usually using indirect indicators, to better understand and predict climate change.

E5.4A Explain the natural mechanism of the greenhouse effect, including comparisons of the major greenhouse gases (water vapor, carbon dioxide, methane, nitrous oxide, and ozone).

E5.4B Describe natural mechanisms that could result in significant changes in climate (e.g., major volcanic eruptions, changes in sunlight received by the earth, and meteorite impacts).

E5.4C Analyze the empirical relationship between the emissions of carbon dioxide, atmospheric carbon dioxide levels, and the average global temperature over the past 150 years.

E5.4D Based on evidence of observable changes in recent history and climate change models, explain the consequences of warmer oceans (including the results of increased evaporation, shoreline and estuarine impacts, oceanic algae growth, and coral bleaching) and changing climatic zones (including the adaptive capacity of the biosphere).

E5.4e Based on evidence from historical climate research (e.g. fossils, varves, ice core data) and climate change models, explain how the current melting of polar ice caps can impact the climatic system .

E5.4f Describe geologic evidence that implies climates were significantly colder at times in the geologic record (e.g., geomorphology, striations, and fossils).

E5.4g Compare and contrast the heat-trapping mechanisms of the major greenhouse gases resulting from emissions (carbon dioxide, methane, nitrous oxide, fluorocarbons) as well as their abundance and heat-trapping capacity.

E5.r4h Use oxygen isotope data to estimate paleotemperature. *(recommended)*

E5.r4i Explain the causes of short-term climate changes such as catastrophic volcanic eruptions and impact of solar system objects. *(recommended)*

E5.r4j Predict the global temperature increase by 2100, given data on the annual trends of CO_2 concentration increase. *(recommended)*

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