SCIENCE v.1.09

# GRADE LEVEL CONTENT EXPECTATIONS

MICHIGAN Department of Education

Office of School Improvement

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SIXTH GRADE

SCIENCE

# GRADE LEVEL CONTENT EXPECTATIONS

6

SCIENCE

v.1.09

***Welcome to Michigan's K-7 Grade Level Content Expectations***

SCIENCE PROCESSES

PHYSICAL SCIENCE

LIFE SCIENCE

EARTH SCIENCE

## Purpose & Overview

In 2004, the Michigan Department of Education embraced the challenge of creating Grade Level Content Expectations in response to the Federal No Child Left Behind Act of 2001. This act mandated the existence of a set of comprehensive state grade level assessments in mathematics and English language arts that are designed based on rigorous grade level content. In addition, assessments for science in elementary, middle, and high school were required. To provide greater clarity for what students are expected to know and be able to do by the end of each grade, expectations for each grade level have been developed for science.

In this global economy, it is essential that Michigan students possess personal, social, occupational, civic, and quantitative literacy. Mastery of the knowledge and essential skills defined in Michigan's Grade Level Content Expectations will increase students' ability to be successful academically, and contribute to the future businesses that employ them and the communities in which they choose to live.

Reflecting best practices and current research, the Grade Level Content Expectations provide a set of clear and rigorous expectations for all students, and provide teachers with clearly defined statements of what students should know and be able to do as they progress through school.

## Development

In developing these expectations, the K-7 Scholar Work Group depended heavily on the *Science Framework for the 2009 National Assessment of Educational Progress* (National Assessment Governing Board, 2006) which has been the gold standard for the high school content expectations. Additionally, the *National Science Education Standards* (National Research Council, 1996), the Michigan Curriculum Framework in Science (2000 version), and the *Atlas for Science Literacy,* Volumes One (AAAS, 2001) and Two (AAAS, 2007), were all continually consulted for developmental guidance. As a further resource for research on learning progressions and curricular designs, *Taking Science to School: Learning and Teaching Science in Grades K-8* (National Research Council, 2007) was extensively utilized. The following statement from this resource was a guiding principle:

"The next generation of science standards and curricula at the national and state levels should be centered on a few core ideas and should expand on them each year, at increasing levels of complexity, across grades K-8. Today's standards are still too broad, resulting in superficial coverage of science that fails to link concepts or develop them over successive grades."

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## Preparing Students for Academic Success

In the hands of teachers, the Grade Level Content Expectations are converted into exciting and engaging learning for Michigan's students. As educators use these expectations, it is critical to keep in mind that content knowledge alone is not sufficient for academic success. Students must also generate questions, conduct investigations, and develop solutions to problems through reasoning and observation. They need to analyze and present their findings which lead to future questions, research, and investigations. Students apply knowledge in new situations, to solve problems by generating new ideas, and to make connections between what they learn in class to the world around them.

Through the collaborative efforts of Michigan educators and creation of professional learning communities, we can enable our young people to attain the highest standards, and thereby open doors for them to have fulfilling and successful lives.

## Understanding the Organizational Structure

The science expectations in this document are organized into disciplines, standards, content statements, and specific content expectations. The content statements in each science standard are broader, more conceptual groupings. The skills and content addressed in these expectations will, in practice, be woven together into a coherent, science curriculum.

To allow for ease in referencing expectations, each expectation has been coded with a discipline, standard, grade-level, and content statement/expectation number.

For example, **P.FM.02.34** indicates:

**P** - Physical Science Discipline

**FM**-Force and Motion Standard

**02**-Second Grade

**34**-Fourth Expectation in the Third Content Statement

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## Why Create a 1.09 Version of the Expectations?

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## Middle School (5-7) Science Organizational Structure

| Discipline 1<br>Science Processes | Discipline 2<br>Physical Science | Discipline 3<br>Life Science | Discipline 4<br>Earth Science |
|---|---|---|---|
| **Standards and Statements** *(and number of Content Expectations in each Statement)* | | | |
| **Inquiry Process (IP)**<br>**Inquiry Analysis and Communication (IA)**<br>**Reflection and Social Implications (RS)** | **Force and Motion (FM)**<br>Force Interactions (2)<br>Force (4)<br>Speed (3)<br>**Energy (EN)**<br>Kinetic and Potential Energy (2)<br>Waves and Energy (3)<br>Energy Transfer (3)<br>Solar Energy Effects (2)<br>**Properties of Matter (PM)**<br>Chemical Properties (1)<br>Elements and Compounds (4)<br>**Changes in Matter (CM)**<br>Changes in State (2)<br>Chemical Changes (3) | **Organization of Living Things (OL)**<br>Cell Functions (4)<br>Growth and Development (2)<br>Animal Systems (2)<br>Producers, Consumers, and Decomposers (2)<br>Photosynthesis (3)<br>**Heredity (HE)**<br>Inherited and Acquired Traits (2)<br>Reproduction (2)<br>**Evolution (EV)**<br>Species Adaptation and Survival (4)<br>Relationships Among Organisms (1)<br>**Ecosystems (EC)**<br>Interactions of Organisms (1)<br>Relationships of Organisms (3)<br>Biotic and Abiotic Factors (2)<br>Environmental Impact of Organisms (2) | **Earth Systems (ES)**<br>Solar Energy (3)<br>Human Consequences (2)<br>Seasons (2)<br>Weather and Climate (4)<br>Water Cycle (2)<br>**Solid Earth (SE)**<br>Soil (4)<br>Rock Formation (1)<br>Plate Tectonics (3)<br>Magnetic Field of Earth (2)<br>**Fluid Earth (FE)**<br>Atmosphere (2)<br>**Earth in Space and Time (ST)**<br>Solar System (1)<br>Solar System Motion (5)<br>Fossils (1)<br>Geologic Time (2) |

## Science Processes: Inquiry Process, Inquiry Analysis and Communication, Reflection, and Social Implications

Sixth grade students have had multiple experiences in science inquiry, practice in investigating a question, and the selection of a variety of resources for information gathering and problem solving. Through the grade level science processes, students gain a greater understanding of the nature and structure of scientific knowledge and the process of its development. Throughout the middle school years, students should be provided with the opportunity to engage in full inquiry experiences that include raising a question based on observations, data sets, and/or research, designing an investigation, gathering information through observation and data collection, analyzing and evaluating information, engaging in science discourse, and formally presenting their findings. Sixth grade students need guidance and practice in the identification of variables and controlling more than one variable in an investigation. They need clarification in recognizing the difference between a scientific explanation and evidence.

With appropriate guidance and experiences, sixth grade students can recognize science as a means of gathering information and confirming or challenging their current beliefs about the natural world, the effect humans and other organisms have on the natural world, and begin to design solutions through science and technology to world challenges.

## Physical Science: Energy and Changes in Matter

Students enter the sixth grade with the knowledge of different forms of energy (sound, light, heat, electrical, and magnetic). They have had the opportunity to explore properties of sound and light, observe heat transfer, construct a simple circuit, observe the interaction between magnetic and non-magnetic material, and finally make an electro-magnetic motor. Sixth grade students deepen their understanding of energy through investigations into kinetic and potential energy and the demonstration of the transformation of kinetic energy. Through the investigation of energy transfer by radiation, conduction, or convection, students are introduced to the concept that energy can be transferred while no energy is lost or gained. Students begin to see the connections among light, heat, sound, electricity, and magnetism. They gain an understanding that energy is an important property of substances and that most changes observed involve an energy transfer. Students will understand energy by observing multiple forms of energy transfer and begin to dispel the misconception that energy is linked to fuel or something that is stored, ready to use, and gets consumed.

Sixth grade students also build on their understanding of changes in matter by exploring states in terms of the arrangement and motion of atoms and molecules. They are given the opportunity to design investigations that provide evidence that mass is conserved as it changes from state to state.

## Life Science: Organization of Living Things and Ecosystems

The study of life science in the elementary curriculum has introduced students to roles organisms play in a food web, their needs to survive, and the physical and behavioral characteristics that help them survive. The elementary student has a beginning understanding of the dependency of organisms on one another and balance in an ecosystem's food web. Sixth grade students build on their prior knowledge by exploring classifications of organisms based on their source of energy (producers, consumers, and decomposers) and distinguish between ways in which organisms obtain energy. The study of ecosystems at this level includes interactions of organisms within populations, communities, and ecosystems including examples in the Great Lakes region. Students recognize patterns in ecosystems and broaden their understanding from the way one species lives in an environment to how populations and communities interact. They explore how populations can be mutually beneficial and how that relationship can lead to interdependency.

The final course of study in ecosystems for the sixth grader includes biotic and abiotic factors in an ecosystem that influence change. Included is the consequence of overpopulation of a species, including humans. Students explore how humans affect change, purposefully and accidentally, and recognize possible consequences for activity and development.

## Earth Science: Solid Earth, Earth in Space and Time

Sixth grade students develop a deeper understanding of the Earth through the exploration of the rock cycle, phenomena that shape the Earth, and Earth's history. In the elementary curriculum, students observed a variety of Earth materials and identified different properties that help sustain life. Sixth grade students explore the formation and weathering of rocks and how different soil types are formed. Their knowledge continues through study of movement of lithospheric plates, major geological events, and layers of the Earth. Students are introduced to the concept of the Earth as a magnet.

The Earth science curriculum includes a deeper exploration into rocks, rock layers, and fossils. They provide evidence of the history of the Earth and are used to measure geologic time. Fossils provide evidence of how life and environmental conditions have changed over long periods of time.

The concept of energy in the sixth grade curriculum is integral throughout the study in physical, life, and Earth science. Students gain a deeper understanding of the concept when encouraged to apply what they know about energy transfer to energy in ecosystems and the rapid and gradual changes on Earth.

## Sixth Grade Science Standards, Statements, and Expectations

***Note:*** *The number in parentheses represents the number of expectations..*

**Discipline 1: Science Processes (S)**

**Standard: Inquiry Process (IP)**

1 Statement (6)

**Standard: Inquiry Analysis and Communication (IA)**

1 Statement (5)

**Standard: Reflection and Social Implications (RS)**

1 Statement (9)

**Discipline 2: Physical Science (P)**

**Standard: Energy (EN)**

Kinetic and Potential Energy (2)

Energy Transfer (2)

**Standard: Changes in Matter (CM)**

Changes in State (2)

**Discipline 3: Life Science (L)**

**Standard: Organization of Living Things (OL)**

Producers, Consumers, and Decomposers (2)

**Standard: Ecosystems (EC)**

Interactions of Organisms (1)

Relationships of Organisms (3)

Biotic and Abiotic Factors (2)

Environmental Impact of Organisms (2)

**Discipline 4: Earth Science (E)**

**Standard: Solid Earth (SE)**

Soil (4)

Rock Formation (1)

Plate Tectonics (3)

Magnetic Field of Earth (2)

**Standard: Earth in Space and Time (ST)**

Fossils (1)

Geologic Time (2)

## SCIENCE PROCESSES

## Inquiry Process

***K-7 Standard S.IP:** Develop an understanding that scientific inquiry and reasoning involves observing, questioning, investigating, recording, and developing solutions to problems.*

**S.IP.M.1 Inquiry involves generating questions, conducting investigations, and developing solutions to problems through reasoning and observation.**

**S.IP.06.11** Generate scientific questions based on observations, investigations, and research.
**S.IP.06.12** Design and conduct scientific investigations.
**S.IP.06.13** Use tools and equipment (spring scales, stop watches, meter sticks and tapes, models, hand lens, thermometer, models, sieves, microscopes) appropriate to scientific investigations.
**S.IP.06.14** Use metric measurement devices in an investigation.
**S.IP.06.15** Construct charts and graphs from data and observations.
**S.IP.06.16** Identify patterns in data.

## Inquiry Analysis and Communication

***K-7 Standard S.IA:** Develop an understanding that scientific inquiry and investigations require analysis and communication of findings, using appropriate technology.*

**S.IA.M.1 Inquiry includes an analysis and presentation of findings that lead to future questions, research, and investigations.**

**S.IA.06.11** Analyze information from data tables and graphs to answer scientific questions.
**S.IA.06.12** Evaluate data, claims, and personal knowledge through collaborative science discourse.
**S.IA.06.13** Communicate and defend findings of observations and investigations using evidence.
**S.IA.06.14** Draw conclusions from sets of data from multiple trials of a scientific investigation.
**S.IA.06.15** Use multiple sources of information to evaluate strengths and weaknesses of claims, arguments, or data.

## Reflection and Social Implications

***K-7 Standard S.RS:** Develop an understanding that claims and evidence for their scientific merit should be analyzed. Understand how scientists decide what constitutes scientific knowledge. Develop an understanding of the importance of reflection on scientific knowledge and its application to new situations to better understand the role of science in society and technology.*

**S.RS.M.1 Reflecting on knowledge is the application of scientific knowledge to new and different situations. Reflecting on knowledge requires careful analysis of evidence that guides decision-making and the application of science throughout history and within society.**

**S.RS.06.11** Evaluate the strengths and weaknesses of claims, arguments, and data.
**S.RS.06.12** Describe limitations in personal and scientific knowledge.
**S.RS.06.13** Identify the need for evidence in making scientific decisions.
**S.RS.06.14** Evaluate scientific explanations based on current evidence and scientific principles.
**S.RS.06.15** Demonstrate scientific concepts through various illustrations, performances, models, exhibits, and activities.
**S.RS.06.16** Design solutions to problems using technology.
**S.RS.06.17** Describe the effect humans and other organisms have on the balance of the natural world.
**S.RS.06.18** Describe what science and technology can and cannot reasonably contribute to society.
**S.RS.06.19** Describe how science and technology have advanced because of the contributions of many people throughout history and across cultures.

## PHYSICAL SCIENCE | Energy

***K-7 Standard P.EN:*** *Develop an understanding that there are many forms of energy (such as heat, light, sound, and electrical) and that energy is transferable by convection, conduction, or radiation. Understand energy can be in motion, called kinetic; or it can be stored, called potential. Develop an understanding that as temperature increases, more energy is added to a system. Understand nuclear reactions in the sun produce light and heat for the Earth.*

**P.EN.M.1 Kinetic and Potential Energy- Objects and substances in motion have kinetic energy. Objects and substances may have potential energy due to their relative positions in a system. Gravitational, elastic, and chemical energy are all forms of potential energy.**

**P.EN.06.11** Identify kinetic or potential energy in everyday situations (for example: stretched rubber band, objects in motion, ball on a hill, food energy).
**P.EN.06.12** Demonstrate the transformation between potential and kinetic energy in simple mechanical systems (for example: roller coasters, pendulums).

**P.EN.M.4 Energy Transfer- Energy is transferred from a source to a receiver by radiation, conduction, and convection. When energy is transferred from one system to another, the quantity of energy before the transfer is equal to the quantity of energy after the transfer. ***

**P.EN.06.41** Explain how different forms of energy can be transferred from one place to another by radiation, conduction, or convection.
**P.EN.06.42** Illustrate how energy can be transferred while no energy is lost or gained in the transfer.

## Changes in Matter

***K-7 Standard P.CM:*** *Develop an understanding of changes in the state of matter in terms of heating and cooling, and in terms of arrangement and relative motion of atoms and molecules. Understand the differences between physical and chemical changes. Develop an understanding of the conservation of mass. Develop an understanding of products and reactants in a chemical change.*

**P.CM.M.1 Changes in State- Matter changing from state to state can be explained by using models which show that matter is composed of tiny particles in motion. When changes of state occur, the atoms and/or molecules are not changed in structure. When the changes in state occur, mass is conserved because matter is not created or destroyed.**

**P.CM.06.11** Describe and illustrate changes in state, in terms of the arrangement and relative motion of the atoms or molecules.
**P.CM.06.12** Explain how mass is conserved as a substance changes from state to state in a closed system. *

# LIFE SCIENCE

## Organization of Living Things

***K-7 Standard L.OL:*** *Develop an understanding that plants and animals (including humans) have basic requirements for maintaining life which include the need for air, water, and a source of energy. Understand that all life forms can be classified as producers, consumers, or decomposers as they are all part of a global food chain where food/energy is supplied by plants which need light to produce food/energy. Develop an understanding that plants and animals can be classified by observable traits and physical characteristics. Understand that all living organisms are composed of cells and they exhibit cell growth and division. Understand that all plants and animals have a definite life cycle, body parts, and systems to perform specific life functions.*

* Revised expectations marked by an asterisk.

**L.OL.M.5 Producers, Consumers, and Decomposers – Producers are mainly green plants that obtain energy from the sun by the process of photosynthesis. All animals, including humans, are consumers that meet their energy needs by eating other organisms or their products. Consumers break down the structures of the organisms they eat to make the materials they need to grow and function. Decomposers, including bacteria and fungi, use dead organisms or their products to meet their energy needs. ***

**L.OL.06.51** Classify producers, consumers, and decomposers based on their source of food (the source of energy and building materials). *

**L.OL.06.52** Distinguish between the ways in which consumers and decomposers obtain energy.

## Ecosystems

***K-7 Standard L.EC:*** *Develop an understanding of the interdependence of the variety of populations, communities and ecosystems, including those in the Great Lakes region. Develop an understanding of different types of interdependence and that biotic (living) and abiotic (non-living) factors affect the balance of an ecosystem. Understand that all organisms cause changes, some detrimental and others beneficial, in the environment where they live.*

**L.EC.M.1 Interactions of Organisms- Organisms of one species form a population. Populations of different organisms interact and form communities. Living communities and nonliving factors that interact with them form ecosystems.**

**L.EC.06.11** Identify and describe examples of populations, communities, and ecosystems including the Great Lakes region. *

**L.EC.M.2 Relationships of Organisms- Two types of organisms may interact with one another in several ways: they may be in a producer/consumer, predator/ prey, or parasite/host relationship. Some organisms may scavenge or decompose another. Relationships may be competitive or mutually beneficial. Some species have become so adapted to each other that neither could survive without the other.**

**L.EC.06.21** Describe common patterns of relationships between and among populations (competition, parasitism, symbiosis, predator/prey).

**L.EC.06.22** Explain how two populations of organisms can be mutually beneficial and how that can lead to interdependency.

**L.EC.06.23** Predict how changes in one population might affect other populations based upon their relationships in the food web.

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**L.EC.M.3 Biotic and Abiotic Factors- The number of organisms and populations an ecosystem can support depends on the biotic (living) resources available and abiotic (nonliving) factors, such as quality of light and water, range of temperatures, and soil composition.**

**L.EC.06.31** Identify the living (biotic) and nonliving (abiotic) components of an ecosystem.
**L.EC.06.32** Identify the factors in an ecosystem that influence changes in population size.

**L.EC.M.4 Environmental Impact of Organisms- All organisms (including humans) cause change in the environment where they live. Some of the changes are harmful to the organism or other organisms, whereas others are helpful.**

**L.EC.06.41** Describe how human beings are part of the ecosystem of the Earth and that human activity can purposefully, or accidentally, alter the balance in ecosystems.
**L.EC.06.42** Predict possible consequences of overpopulation of organisms, including humans, (for example: species extinction, resource depletion, climate change, pollution).

## EARTH SCIENCE

## Solid Earth

***K-7 Standard E.SE:*** *Develop an understanding of the properties of Earth materials and how those properties make materials useful. Understand gradual and rapid changes in Earth materials and features of the surface of Earth. Understand magnetic properties of Earth.*

**E.SE.M.1 Soil- Soils consist of weathered rocks and decomposed organic materials from dead plants, animals, and bacteria. Soils are often found in layers with each having a different chemical composition and texture.**

**E.SE.06.11** Explain how physical and chemical weathering lead to erosion and the formation of soils and sediments.
**E.SE.06.12** Explain how waves, wind, water, and glacier movement, shape and reshape the land surface of the Earth by eroding rock in some areas and depositing sediments in other areas.
**E.SE.06.13** Describe how soil is a mixture made up of weather eroded rock and decomposed organic material.
**E.SE.06.14** Compare different soil samples based on particle size and texture.

**E.SE.M.4 Rock Formation- Rocks and rock formations bear evidence of the minerals, materials, temperature/pressure conditions, and forces that created them.**

**E.SE.06.41** Compare and contrast the formation of rock types (igneous, metamorphic, and sedimentary) and demonstrate the similarities and differences using the rock cycle model.

**E.SE.M.5 Plate Tectonics- The lithospheric plates of the Earth constantly move, resulting in major geological events, such as earthquakes, volcanic eruptions, and mountain building.**

**E.SE.06.51** Explain plate tectonic movement and how the lithospheric plates move centimeters each year.
**E.SE.06.52** Demonstrate how major geological events (earthquakes, volcanic eruptions, mountain building) result from these plate motions.
**E.SE.06.53** Describe layers of the Earth as a lithosphere (crust and upper mantle), convecting mantle, and dense metallic core.

**E.SE.M.6 Magnetic Field of Earth- Earth as a whole has a magnetic field that is detectable at the surface with a compass.**

**E.SE.06.61** Describe the Earth as a magnet and compare the magnetic properties of the Earth to that of a natural or manufactured magnet. *
**E.SE.06.62** Explain how a compass works using the magnetic field of the Earth, and how a compass is used for navigation on land and sea.

## Earth in Space and Time

***K-7 Standard E.ST:*** *Develop an understanding that the sun is the central and largest body in the solar system and that Earth and other objects in the sky move in a regular and predictable motion around the sun. Understand that those motions explain the day, year, moon phases, eclipses and the appearance of motion of objects across the sky. Understand that gravity is the force that keeps the planets in orbit around the sun and governs motion in the solar system. Develop an understanding that fossils and layers of Earth provide evidence of the history of Earth's life forms, changes over long periods of time, and theories regarding Earth's history and continental drift.*

**E.ST.M.3 Fossils- Fossils provide important evidence of how life and environmental conditions have changed in a given location.**

**E.ST.06.31** Explain how rocks and fossils are used to understand the age and geological history of the Earth (timelines and relative dating, rock layers).

* Revised expectations marked by an asterisk.

**E.ST.M.4 Geologic Time- Earth processes seen today (erosion, mountain building, and glacier movement) make possible the measurement of geologic time through methods such as observing rock sequences and using fossils to correlate the sequences at various locations.**

**E.ST.06.41** Explain how Earth processes (erosion, mountain building, and glacier movement) are used for the measurement of geologic time through observing rock layers.

**E.ST.06.42** Describe how fossils provide important evidence of how life and environmental conditions have changed.

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|---|---|---|---|
| **Standards and Statements** *(and number of Content Expectations in each Statement)* | | | |
| **Inquiry Process (IP)**<br>**Inquiry Analysis and Communication (IA)**<br>**Reflection and Social Implications (RS)** | **Force and Motion (FM)**<br>Force Interactions (2)<br>Force (4)<br>Speed (3)<br>**Energy (EN)**<br>Kinetic and Potential Energy (2)<br>Waves and Energy (3)<br>Energy Transfer (3)<br>Solar Energy Effects (2)<br>**Properties of Matter (PM)**<br>Chemical Properties (1)<br>Elements and Compounds (4)<br>**Changes in Matter (CM)**<br>Changes in State (2)<br>Chemical Changes (3) | **Organization of Living Things (OL)**<br>Cell Functions (4)<br>Growth and Development (2)<br>Animal Systems (2)<br>Producers, Consumers, and Decomposers (2)<br>Photosynthesis (3)<br>**Heredity (HE)**<br>Inherited and Acquired Traits (2)<br>Reproduction (2)<br>**Evolution (EV)**<br>Species Adaptation and Survival (4)<br>Relationships Among Organisms (1)<br>**Ecosystems (EC)**<br>Interactions of Organisms (1)<br>Relationships of Organisms (3)<br>Biotic and Abiotic Factors (2)<br>Environmental Impact of Organisms (2) | **Earth Systems (ES)**<br>Solar Energy (3)<br>Human Consequences (2)<br>Seasons (2)<br>Weather and Climate (4)<br>Water Cycle (2)<br>**Solid Earth (SE)**<br>Soil (4)<br>Rock Formation (1)<br>Plate Tectonics (3)<br>Magnetic Field of Earth (2)<br>**Fluid Earth (FE)**<br>Atmosphere (2)<br>**Earth in Space and Time (ST)**<br>Solar System (1)<br>Solar System Motion (5)<br>Fossils (1)<br>Geologic Time (2) |

### Science Processes: Inquiry Process, Inquiry Analysis and Communication, Reflection, and Social Implications

The seventh grade content expectations present the final opportunity for the middle school learners to refine and develop their inquiry skills prior to the introduction of the high school curriculum. Students should be able to recognize that different kinds of questions suggest different approaches for scientific investigation. Students should be able to generate a variety of questions through observation, sets of data, manipulation of variables, investigations, and research. They further develop and sharpen their skills in measurement and the use of tools and scientific equipment. They collect and organize their own sets of data into charts and graphs, make sense of their findings, evaluate and analyze their own data as well as the data of others, and evaluate the strengths and weaknesses of their findings and the claims of others. Students recognize the importance of collaborative science discourse. Learners understand that science investigations and advances may result in new ideas and areas of study generating new methods and possibly resulting in new investigations.

Reflection and social implications are the application of the students' new knowledge and affects their decision making and their perception of the effect humans, scientific discovery, and technology have on society and the natural world.

## Physical Science: Energy, Properties of Matter, Changes in Matter

Seventh grade students continue their exploration into the concept of energy through the exploration of light energy and solar energy effects. Students gain a greater understanding of the role of the sun's warming and lighting of the Earth, and how light energy is transferred to chemical energy through photosynthesis. The transfer of energy is studied through examples of waves (sound, seismic, and water) and how waves transfer energy when they interact with matter.

Their earlier studies of properties of matter emphasized observable physical properties. Seventh grade students explore a more in-depth study of physical properties (boiling point, density, and color) and chemical properties of matter (flammability, pH, acid-base indicators, and reactivity). Students are introduced to organization of the Periodic Table of the Elements and recognize the atom as the smallest component that makes up an element.

Seventh grade students draw upon their knowledge of properties of matter and use evidence to describe physical and chemical change. They recognize that when a chemical change occurs, a new substance is produced and that the new substance has different physical and chemical properties than the original substance. Students describe evidence of chemical change as a change in color, gas formation, solid formation, and temperature change.

## Life Science: Organization of Living Things and Heredity

Seventh grade students expand their investigations of living things to include the study of cells. They demonstrate that all organisms are composed of cells and that multi-cellular organisms and single cellular organisms exist in ecosystems. The seventh grade study of cells includes how cells make up different body tissues, organs, and organ systems and are specialized in their functions. Cell division is explored to help the students describe growth and development. Seventh grade students have the fine motor skills and conceptual development to use a light microscope and accurately interpret what they see. This enhances their introduction to cells and microorganisms, establishing a foundation for molecular biology at the high school level.

In the seventh grade content expectations, students expand their knowledge to include how characteristics of living things are passed on through generations, both asexually and sexually. Seventh grade students are able to understand that genetic material carries information. They compare and contrast the advantages of sexual vs. asexual reproduction, and recognize that reproduction is a characteristic of all living things and necessary for the continuation of every species.

## Earth Science: Earth Systems and Fluid Earth

The primary focus of the Earth science content expectations is understanding the relationship between the sun's warming of the Earth, the water cycle, and weather and climate. In the sixth grade Earth science curriculum, students studied the rock cycle and physical and chemical weathering. The seventh grade units of study explore another Earth cycle in the context of the water cycle and the composition of the atmosphere. Students investigate the sun's warming of the atmosphere, land, and water, and how it affects the movement of water through the atmosphere, weather, and climate. Their knowledge of weather goes beyond the more basic observations of weather from the elementary curriculum to include the frontal boundaries, major air masses, and the jet stream. The reflection of their knowledge is applied to how human activities have changed the land, oceans, and atmosphere, and the implications of pollution, climate change, and threatening or endangering species.

## Seventh Grade Science Standards, Statements, and Expectations

***Note:*** *The number in parentheses represents the number of expectations.*

### Discipline 1: Science Processes (S)

**Standard: Inquiry Process (IP)**
- 1 Statement (6)

**Standard: Inquiry Analysis and Communication (IA)**
- 1 Statement (5)

**Standard: Reflection and Social Implications (RS)**
- 1 Statement (9)

### Discipline 2: Physical Science (P)

**Standard: Energy (EN)**
- Waves and Energy (3)
- Energy Transfer (1)
- Solar Energy Effects (2)

**Standard: Properties of Matter (PM)**
- Chemical Properties (1)
- Elements and Compounds (4)

**Standard: Changes in Matter (CM)**
- Chemical Changes (3)

### Discipline 3: Life Science (L)

**Standard: Organization of Living Things (OL)**
- Cell Functions (4)
- Growth and Development (2)
- Photosynthesis (3)

**Standard: Heredity (HE)**
- Reproduction (2)

### Discipline 4: Earth Science (E)

**Standard: Earth Systems (ES)**
- Solar Energy (3)
- Human Consequences (2)
- Weather and Climate (4)
- Water Cycle (2)

**Standard: Fluid Earth (FE)**
- Atmosphere (2)

## SCIENCE PROCESSES

## Inquiry Process

***K-7 Standard S.IP:*** *Develop an understanding that scientific inquiry and reasoning involves observing, questioning, investigating, recording, and developing solutions to problems.*

**S.IP.M.1 Inquiry involves generating questions, conducting investigations, and developing solutions to problems through reasoning and observation.**

**S.IP.07.11** Generate scientific questions based on observations, investigations, and research.
**S.IP.07.12** Design and conduct scientific investigations.
**S.IP.07.13** Use tools and equipment (spring scales, stop watches, meter sticks and tapes, models, hand lens, thermometer, models, sieves, microscopes, hot plates, pH meters) appropriate to scientific investigations.
**S.IP.07.14** Use metric measurement devices in an investigation.
**S.IP.07.15** Construct charts and graphs from data and observations.
**S.IP.07.16** Identify patterns in data.

## Inquiry Analysis and Communication

***K-7 Standard S.IA:*** *Develop an understanding that scientific inquiry and investigations require analysis and communication of findings, using appropriate technology.*

**S.IA.M.1 Inquiry includes an analysis and presentation of findings that lead to future questions, research, and investigations.**

**S.IA.07.11** Analyze information from data tables and graphs to answer scientific questions.
**S.IA.07.12** Evaluate data, claims, and personal knowledge through collaborative science discourse.
**S.IA.17.13** Communicate and defend findings of observations and investigations.
**S.IA.07.14** Draw conclusions from sets of data from multiple trials of a scientific investigation to draw conclusions.
**S.IA.07.15** Use multiple sources of information to evaluate strengths and weaknesses of claims, arguments, or data.

## Reflection and Social Implications

***K-7 Standard S.RS:*** *Develop an understanding that claims and evidence for their scientific merit should be analyzed. Understand how scientists decide what constitutes scientific knowledge. Develop an understanding of the importance of reflection on scientific knowledge and its application to new situations to better understand the role of science in society and technology.*

**S.RS.M.1 Reflecting on knowledge is the application of scientific knowledge to new and different situations. Reflecting on knowledge requires careful analysis of evidence that guides decision-making and the application of science throughout history and within society.**

**S.RS.07.11** Evaluate the strengths and weaknesses of claims, arguments, and data.
**S.RS.07.12** Describe limitations in personal and scientific knowledge.
**S.RS.07.13** Identify the need for evidence in making scientific decisions.
**S.RS.07.14** Evaluate scientific explanations based on current evidence and scientific principles.
**S.RS.07.15** Demonstrate scientific concepts through various illustrations, performances, models, exhibits, and activities.
**S.RS.07.16** Design solutions to problems using technology.
**S.RS.07.17** Describe the effect humans and other organisms have on the balance of the natural world.
**S.RS.07.18** Describe what science and technology can and cannot reasonably contribute to society.
**S.RS.07.19** Describe how science and technology have advanced because of the contributions of many people throughout history and across cultures.

## PHYSICAL SCIENCE

## Energy

***K-7 Standard P.EN:*** *Develop an understanding that there are many forms of energy (such as heat, light, sound, and electrical) and that energy is transferable by convection, conduction, or radiation. Understand energy can be in motion, called kinetic; or it can be stored, called potential. Develop an understanding that as temperature increases, more energy is added to a system. Understand nuclear reactions in the sun produce light and heat for the Earth.*

**P.EN.M.3 Waves and Energy-Waves have energy and transfer energy when they interact with matter. Examples of waves include sound waves, seismic waves, waves on water, and light waves.**

**P.EN.07.31** Identify examples of waves, including sound waves, seismic waves, and waves on water.
**P.EN.07.32** Describe how waves are produced by vibrations in matter.
**P.EN.07.33** Demonstrate how waves transfer energy when they interact with matter (for example: tuning fork in water, waves hitting a beach, earthquake knocking over buildings).

***P.EN.M.4 Energy Transfer- Energy is transferred from a source to a receiver by radiation, conduction, and convection. When energy is transferred from one system to another, the quantity of energy before the transfer is equal to the quantity of energy after the transfer. ****

**P.EN.07.43** Explain how light energy is transferred to chemical energy through the process of photosynthesis.

* Revised expectations marked by an asterisk.

**P.EN.M.6 Solar Energy Effects- Nuclear reactions take place in the sun producing heat and light. Only a tiny fraction of the light energy from the sun reaches Earth, providing energy to heat the Earth.**

**P.EN.07.61** Identify that nuclear reactions take place in the sun, producing heat and light.
**P.EN.07.62** Explain how only a tiny fraction of light energy from the sun is transformed to heat energy on Earth.

## Properties of Matter

***K-7 Standard P.PM:*** *Develop an understanding that all matter has observable attributes with physical and chemical properties that are described, measured, and compared. Understand that states of matter exist as solid, liquid, or gas; and have physical and chemical properties. Understand all matter is composed of combinations of elements, which are organized by common attributes and characteristics on the Periodic Table. Understand that substances can be classified as mixtures or compounds and according to their physical and chemical properties.*

**P.PM.M.1 Chemical Properties- Matter has chemical properties. The understanding of chemical properties helps to explain how new substances are formed.**

**P.PM.07.11** Classify substances by their chemical properties (flammability, pH, and reactivity). *

**P.PM.M.2 Elements and Compounds- Elements are composed of a single kind of atom that are grouped into families with similar properties on the periodic table. Compounds are composed of two or more different elements. Each element and compound has a unique set of physical and chemical properties such as boiling point, density, color, conductivity, and reactivity.**

**P.PM.07.21** Identify the smallest component that makes up an element.
**P.PM.07.22** Describe how the elements within the Periodic Table are organized by similar properties into families (highly reactive metals, less reactive metals, highly reactive nonmetals, and some almost completely non-reactive gases).
**P.PM.07.23** Illustrate the structure of molecules using models or drawings (water, carbon dioxide, table salt). *
**P.PM.07.24** Describe examples of physical and chemical properties of elements and compounds (boiling point, density, color, conductivity, reactivity). *

* Revised expectations marked by an asterisk.

## Changes in Matter

***K-7 Standard P.CM:*** *Develop an understanding of changes in the state of matter in terms of heating and cooling, and in terms of arrangement and relative motion of atoms and molecules. Understand the differences between physical and chemical changes. Develop an understanding of the conservation of mass. Develop an understanding of products and reactants in a chemical change.*

**P.CM.M.2 Chemical Changes- Chemical changes occur when two elements and/or compounds react (including decomposing) to produce new substances. These new substances have different physical and chemical properties than the original elements and/or compounds. During the chemical change, the number and kind of atoms in the reactants are the same as the number and kind of atoms in the products. Mass is conserved during chemical changes. The mass of the reactants is the same as the mass of the products. ***

**P.CM.07.21** Identify evidence of chemical change through color, gas formation, solid formation, and temperature change.

**P.CM.07.22** Compare and contrast the chemical properties of a new substance with the original after a chemical change.

**P.CM.07.23** Describe the physical properties and chemical properties of the products and reactants in a chemical change.

# LIFE SCIENCE

## Organization of Living Things

***K-7 Standard L.OL:*** *Develop an understanding that plants and animals (including humans) have basic requirements for maintaining life which include the need for air, water, and a source of energy. Understand that all life forms can be classified as producers, consumers, or decomposers as they are all part of a global food chain where food/energy is supplied by plants which need light to produce food/energy. Develop an understanding that plants and animals can be classified by observable traits and physical characteristics. Understand that all living organisms are composed of cells and they exhibit cell growth and division. Understand that all plants and animals have a definite life cycle, body parts, and systems to perform specific life functions.*

* Revised expectations marked by an asterisk.

**L.OL.M.2 Cell Functions- All organisms are composed of cells, from one cell to many cells. In multicellular organisms, specialized cells perform specialized functions. Organs and organ systems are composed of cells, and function to serve the needs of cells for food, air, and waste removal. The way in which cells function is similar in all living organisms.**

**L.OL.07.21** Recognize that all organisms are composed of cells (single cell organisms, multicellular organisms).
**L.OL.07.22** Explain how cells make up different body tissues, organs, and organ systems.
**L.OL.07.23** Describe how cells in all multicellular organisms are specialized to take in nutrients, which they use to provide energy for the work that cells do and to make the materials that a cell or organism needs.
**L.OL.07.24** Recognize that cells function in a similar way in all organisms.

**L.OL.M.3- Growth and Development- Following fertilization, cell division produces a small cluster of cells that then differentiate by appearance and function to form the basic tissue of multicellular organisms. ***

**L.OL.07.31** Describe growth and development in terms of increase of cell number and/or cell size.
**L.OL.07.32** Examine how through cell division, cells can become specialized for specific functions.

**L.OL.M.6 Photosynthesis- Plants are producers; they use the energy from light to make sugar molecules from the atoms of carbon dioxide and water. Plants use these sugars along with minerals from the soil to form fats, proteins, and carbohydrates. These products can be used immediately, incorporated into the cells of a plant as the plant grows, or stored for later use.**

**L.OL.07.61** Recognize the need for light to provide energy for the production of carbohydrates, proteins and fats.
**L.OL.07.62** Explain that carbon dioxide and water are used to produce carbohydrates, proteins, and fats.
**L.OL.07.63** Describe evidence that plants make, use and store food.

* Revised expectations marked by an asterisk.

## Heredity

***K-7 Standard L.HE:*** *Develop an understanding that all life forms must reproduce to survive. Understand that characteristics of mature plants and animals may be inherited or acquired and that only inherited traits are passed on to their young. Understand that inherited traits can be influenced by changes in the environment and by genetics.*

**L.HE.M.2 Reproduction- Reproduction is a characteristic of all living systems; because no individual organism lives forever, reproduction is essential to the continuation of every species. Some organisms reproduce asexually. Other organisms reproduce sexually.**

**L.HE.07.21** Compare how characteristics of living things are passed on through generations, both asexually and sexually.

**L.HE.07.22** Compare and contrast the advantages and disadvantages of sexual vs. asexual reproduction.

## EARTH SCIENCE

## Earth Systems

***K-7 Standard E.ES:*** *Develop an understanding of the warming of the Earth by the sun as the major source of energy for phenomenon on Earth and how the sun's warming relates to weather, climate, seasons, and the water cycle. Understand how human interaction and use of natural resources affects the environment.*

**E.ES.M.1 Solar Energy- The sun is the major source of energy for phenomena on the surface of the Earth.**

**E.ES.07.11** Demonstrate, using a model or drawing, the relationship between the warming by the sun of the Earth and the water cycle as it applies to the atmosphere (evaporation, water vapor, warm air rising, cooling, condensation, clouds).

**E.ES.07.12** Describe the relationship between the warming of the atmosphere of the Earth by the sun and convection within the atmosphere and oceans.

**E.ES.07.13** Describe how the warming of the Earth by the sun produces winds and ocean currents.

**E.ES.M.4 Human Consequences- Human activities have changed the land, oceans, and atmosphere of the Earth resulting in the reduction of the number and variety of wild plants and animals, sometimes causing extinction of species.**

**E.ES.07.41** Explain how human activities (surface mining, deforestation, overpopulation, construction and urban development, farming, dams, landfills, and restoring natural areas) change the surface of the Earth and affect the survival of organisms.

**E.ES.07.42** Describe the origins of pollution in the atmosphere, geosphere, and hydrosphere, (car exhaust, industrial emissions, acid rain, and natural sources), and how pollution impacts habitats, climatic change, threatens or endangers species.

**E.ES.M.7 Weather and Climate- Global patterns of atmospheric and oceanic movement influence weather and climate.**

**E.ES.07.71** Compare and contrast the difference and relationship between climate and weather.

**E.ES.07.72** Describe how different weather occurs due to the constant motion of the atmosphere from the energy of the sun reaching the surface of the Earth.

**E.ES.07.73** Explain how the temperature of the oceans affects the different climates on Earth because water in the oceans holds a large amount of heat.

**E.ES.07.74** Describe weather conditions associated with frontal boundaries (cold, warm, stationary, and occluded) and the movement of major air masses and the jet stream across North America using a weather map.

**E.ES.M.8 Water Cycle- Water circulates through the four spheres of the Earth in what is known as the "water cycle."**

**E.ES.07.81** Explain the water cycle and describe how evaporation, transpiration, condensation, cloud formation, precipitation, infiltration, surface runoff, ground water, and absorption occur within the cycle.

**E.ES.07.82** Analyze the flow of water between the components of a watershed, including surface features (lakes, streams, rivers, wetlands) and groundwater.

## Fluid Earth

***K-7 Standard E.FE:*** *Develop an understanding that Earth is a planet nearly covered with water and that water on Earth can be found in three states, solid, liquid, and gas. Understand how water on Earth moves in predictable patterns. Understand Earth's atmosphere as a mixture of gases and water vapor.*

**E.FE.M.1 Atmosphere- The atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor. The atmosphere has different physical and chemical composition at different elevations.**

**E.FE.07.11** Describe the atmosphere as a mixture of gases.
**E.FE.07.12** Compare and contrast the composition of the atmosphere at different elevations.

# Michigan High School Science

# EARTH SCIENCE

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

CE • **RIGOR** • RELEVANCE • RELATIONSHIPS • RIGOR • RE
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IPS • **RELATIONSHIPS** • RIGOR • RELEVANCE • RELAT

MICHIGAN Department of Education
10/06

# 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)*