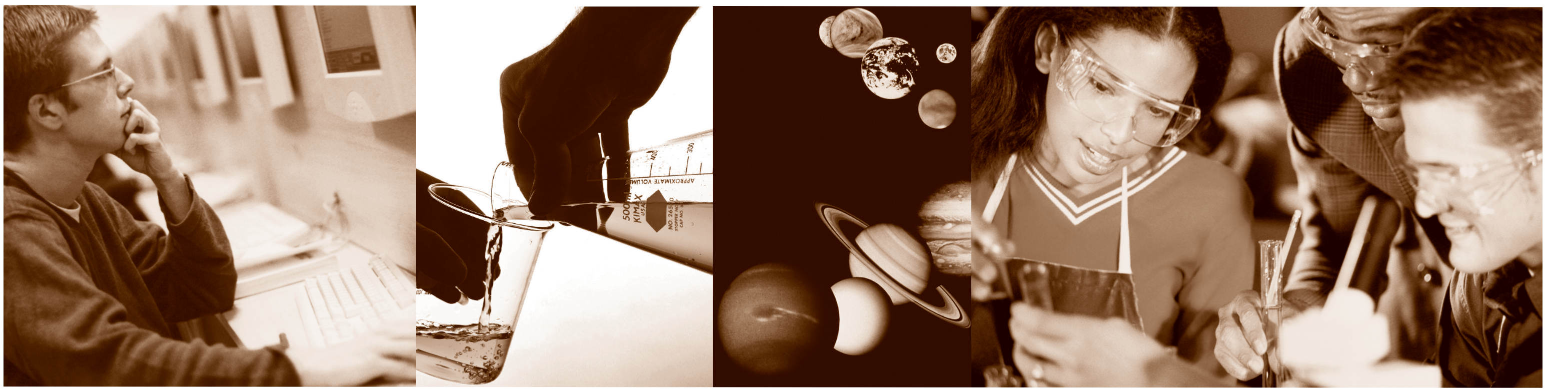
High School Content Expectations



SCIENCE

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

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

Why Develop Content Standards and Expectations for High School?

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

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

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

An Overview

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

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

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

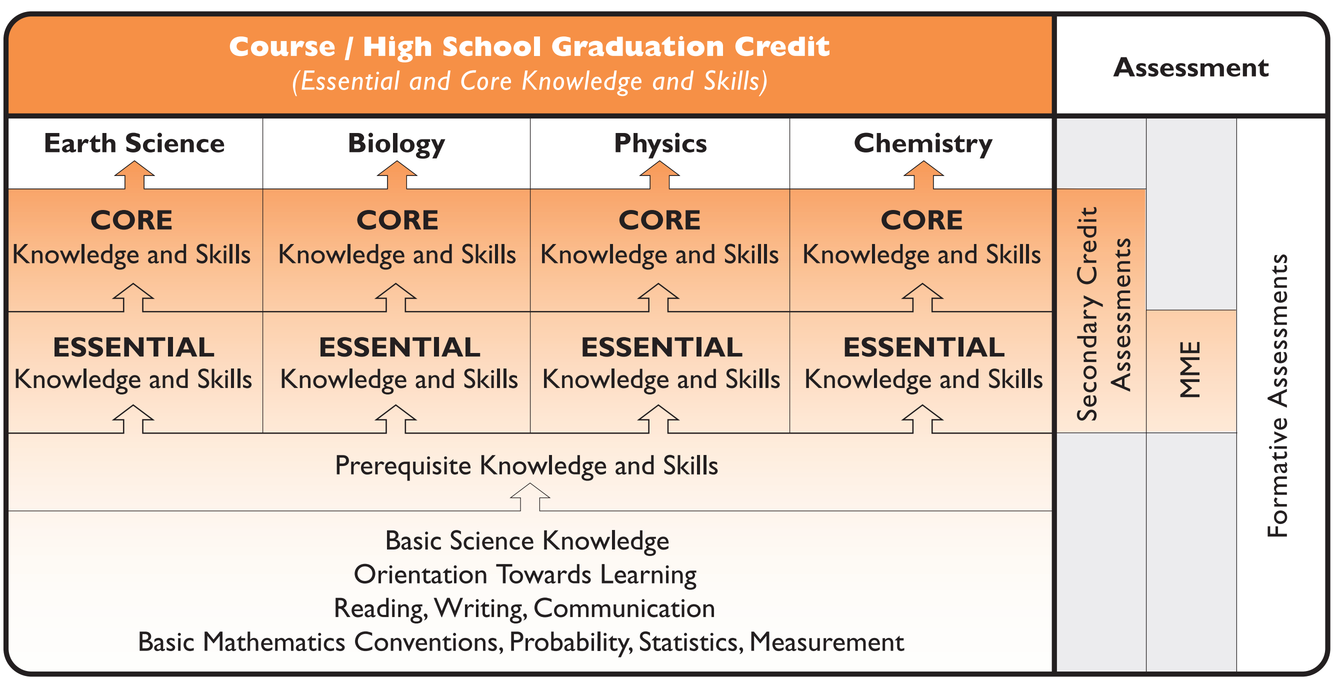
Useful and Connected Knowledge for All Students

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

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

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

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



Preparing Students for Successful Post-Secondary Engagement

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

Successful Post-Secondary Engagement

Practices of Science Literacy

Communicate accurately and effectively...

Identifying Science Principles

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

Using Science Principles

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

Scientific Inquiry

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

Reflection and Social Implications

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

State / National Landscape

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

State / Federal Expectations

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

Michigan High School Science Content Standards and Expectations

Earth Science

Biology

Physics

Chemistry

Models for District Alignment / Mapping

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

Other MI Documents / Programs

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

K-8 Educational Experience

Content Knowledge

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

Learning Processes

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

This chart includes talking points for professional development.

Practices of Science Literacy

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

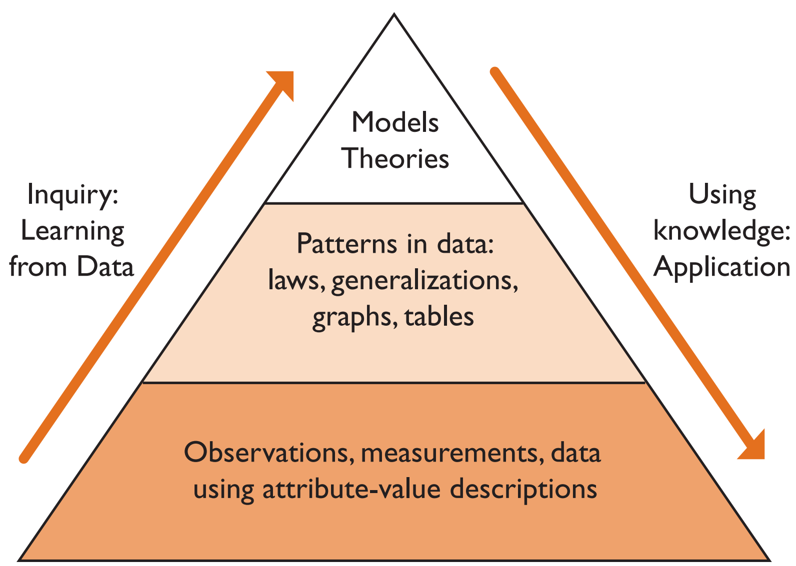


Figure 1: Knowledge and practices of model-based reasoning

Identifying Science Principles

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

Identifying Science Principles comprises the following general types of practices:

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

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

Using Science Principles

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

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

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

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

Scientific Inquiry

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

Scientific Inquiry comprises the following general types of performance expectations:

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

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

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

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

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

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

Scientific Reflection and Social Implications

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

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

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

Organization of the Expectations

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

Disciplines

Earth Science, Biology, Physics, and Chemistry

Organization of Each Standard

Each standard includes three parts:

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

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

Standard Statement

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

Content Statements

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

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

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

Performance Expectations

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

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

Michigan High School Science

BIOLOGY

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

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BIOLOGY (B)

The life sciences are changing in ways that have important implications for high school biology. Many of these changes concern our understanding of the largest and the smallest living systems. Molecular biology continues to produce new insights into how living systems work and how they are connected with one another, as well as new technologies, such as recombinant DNA, that have profound implications for our health, our lifestyles, and our political and economic systems. Equally important are changes in ecology, a traditional biological discipline which plays a key role in the emerging interdisciplinary field of environmental science. Ecologists are working together with oceanographers, atmospheric scientists, and social scientists to study the coupled human and natural systems that support all life on earth, and to understand how those systems are changing in response to growing human populations and our technologies. Our students will need to understand these changing fields in order to be healthy and responsible citizens and productive workers.

An understanding of biology begins with appreciation of the diversity and the structures of living systems. The structure of living systems directly influences how they carry out their life functions. Reasoning about living systems often involves relating different levels of organization, from the molecule to the biosphere, and understanding how living systems are structured at each level. Life processes in a cell are based on molecular interactions which keep the internal environment relatively constant. Cells are composed of highly organized structures called organelles. Cells are the smallest unit of life that can assimilate energy, reproduce, and react to the environment. A collection of cells with a common function forms a tissue and several kinds of tissues form an organ. Together many organs form an organ system such as the digestive system. A multicellular organism is the composite of cells, tissues, and organs. All organisms are interconnected in populations, communities, and ecosystems.

All living systems function in ways that are consistent with basic physical laws, including conservation of matter and energy. Transformations of matter and energy are crucial to the functions of every living system, from the molecular to the global level. The food-making process of photosynthesis generates the energy source, in the form of organic compounds, for all living things. Organic compounds transfer matter and energy through ecosystems via food chains and webs. The energy found in organic chemical bonds is changed to usable cellular energy through the process of cellular respiration. Photosynthesis and cellular respiration are key processes through which living systems exchange matter and energy with the non-living environment, participating in biogeochemical cycles that are being altered in unprecedented ways by human populations and human technologies.

In addition to transforming matter and energy, living systems have a unique ability to maintain their complex organization over time. The information that enables them to do this is stored in the genomes of every living cell. Genetic information is passed from parent to offspring in the form of gametes. Fertilization unites the genetic information from both parents creating a unique individual. Organisms within a species are generally similar because they posses very similar genetic material. However, genetic mixing and occasional mutation result in differences among individuals. Over time, changes in genetic information can affect the size, diversity, and genetic composition of populations, a process called biological evolution.

It is widely accepted that Earth's present day life forms have evolved from common ancestors by processes that include natural selection. In the scientific community, evolution has been a unifying principle that provides a framework for organizing most of biological knowledge into a coherent picture. It has been accepted by the scientific community that evidence for evolution is found in the fossil record and is indicated by anatomical and chemical similarities evident within the diversity of existing organisms.

Biology Content Statement Outline

STANDARD B1	**Inquiry, Reflection, and Social Implications**	
	B1.1	Scientific Inquiry
	B1.2	Scientific Reflection and Social Implications
STANDARD B2	**Organization and Development of Living Systems**	
	L2.p1	Cells *(prerequisite)*
	L2.p2	Cell Function *(prerequisite)*
	L2.p3	Plants as Producers *(prerequisite)*
	L2.p4	Animals as Consumers *(prerequisite)*
	L2.p5	Common Elements *(prerequisite)*
	B2.1	Transformation of Matter and Energy in Cells
	B2.1x	Cell Differentiation
	B2.2	Organic Molecules
	B2.2x	Proteins
	B2.3	Maintaining Environmental Stability
	B2.3x	Homeostasis
	B2.4	Cell Specialization
	B2.5	Living Organism Composition
	B2.5x	Energy Transfer
	B2.6x	Internal/External Cell Regulation
STANDARD B3	**Interdependence of Living Systems and the Environment**	
	L3.p1	Populations, Communities, and Ecosystems *(prerequisite)*
	L3.p2	Relationships Among Organisms *(prerequisite)*
	L3.p3	Factors Influencing Ecosystems *(prerequisite)*
	L3.p4	Human Impact on Ecosystems *(prerequisite)*
	B3.1	Photosynthesis and Respiration
	B3.2	Ecosystems
	B3.3	Element Recombination
	B3.4	Changes in Ecosystems
	B3.4x	Human Impact
	B3.5	Populations
	B3.5x	Environmental Factors
STANDARD B4	**Genetics**	
	L4.p1	Reproduction *(prerequisite)*
	L4.p2	Heredity and Environment *(prerequisite)*
	B4.1	Genetics and Inherited Traits
	B4.2	DNA
	B4.2x	DNA, RNA, and Protein Synthesis
	B4.3	Cell Division – Mitosis and Meiosis
	B4.4x	Genetic Variation
	B4.r5x	Recombinant DNA *(recommended)*
STANDARD B5	**Evolution and Biodiversity**	
	L5.p1	Survival and Extinction *(prerequisite)*
	L5.p2	Classification *(prerequisite)*
	B5.1	Theory of Evolution
	B5.2	Molecular Evidence
	B5.3	Natural Selection

STANDARD B1: 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.

B1.1 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.

B1.1A Generate new questions that can be investigated in the laboratory or field.

B1.1B 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.

B1.1C 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).

B1.1D Identify patterns in data and relate them to theoretical models.

B1.1E Describe a reason for a given conclusion using evidence from an investigation.

B1.1f Predict what would happen if the variables, methods, or timing of an investigation were changed.

B1.1g Use empirical evidence to explain and critique the reasoning used to draw a scientific conclusion or explanation.

B1.1h Design and conduct a systematic scientific investigation that tests a hypothesis. Draw conclusions from data presented in charts or tables.

B1.1i Distinguish between scientific explanations that are regarded as current scientific consensus and the emerging questions that active researchers investigate.

B1.2 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.

B1.2A Critique whether or not specific questions can be answered through scientific investigations.

B1.2B Identify and critique arguments about personal or societal issues based on scientific evidence.

B1.2C Develop an understanding of a scientific concept by accessing information from multiple sources. Evaluate the scientific accuracy and significance of the information.

B1.2D Evaluate scientific explanations in a peer review process or discussion format.

B1.2E Evaluate the future career and occupational prospects of science fields.

B1.2f Critique solutions to problems, given criteria and scientific constraints.

B1.2g Identify scientific tradeoffs in design decisions and choose among alternative solutions.

B1.2h Describe the distinctions between scientific theories, laws, hypotheses, and observations.

B1.2i Explain the progression of ideas and explanations that leads to science theories that are part of the current scientific consensus or core knowledge.

B1.2j Apply science principles or scientific data to anticipate effects of technological design decisions.

B1.2k Analyze how science and society interact from a historical, political, economic, or social perspective.

STANDARD B2: ORGANIZATION AND DEVELOPMENT OF LIVING SYSTEMS

Students describe the general structure and function of cells. They can explain that all living systems are composed of cells and that organisms may be unicellular or multicellular. They understand that cells are composed of biological macromolecules and that the complex processes of the cell allow it to maintain a stable internal environment necessary to maintain life. They make predictions based on these understandings.

L2.p1 Cells *(prerequisite)*

All organisms are composed of cells, from just one cell to many cells. Water accounts for more than two-thirds of the weight of a cell, which gives cells many of their properties. In multicellular organisms, specialized cells perform specialized functions. Organs and organ systems are composed of cells and function to serve the needs of organisms for food, air, and waste removal. The way in which cells function is similar in all living organisms. *(prerequisite)*

L2.p1A Distinguish between living and nonliving systems. *(prerequisite)*

L2.p1B Explain the importance of both water and the element carbon to cells. *(prerequisite)*

L2.p1C Describe growth and development in terms of increase in cell number, cell size, and/or cell products. *(prerequisite)*

L2.p1D Explain how the systems in a multicellular organism work together to support the organism. *(prerequisite)*

L2.p1E Compare and contrast how different organisms accomplish similar functions (e.g., obtain oxygen for respiration, and excrete waste). *(prerequisite)*

L2.p2 Cell Function *(prerequisite)*

Cells carry out the many functions needed to sustain life. They grow and divide, thereby producing more cells. Food is used to provide energy for the work that cells do and is a source of the molecular building blocks from which needed materials are assembled. *(prerequisite)*

L2.p2A Describe how organisms sustain life by obtaining, transporting, transforming, releasing, and eliminating matter and energy. *(prerequisite)*

L2.p2B Describe the effect of limiting food to developing cells. *(prerequisite)*

L2.p3 Plants as Producers *(prerequisite)*

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. This food can be used immediately, incorporated into the cells of a plant as the plant grows, or stored for later use. *(prerequisite)*

L2.p3A Explain the significance of carbon in organic molecules. *(prerequisite)*

L2.p3B Explain the origins of plant mass. *(prerequisite)*

L2.p3C Predict what would happen to plants growing in low carbon dioxide atmospheres. *(prerequisite)*

L2.p3D Explain how the roots of specific plants grow. *(prerequisite)*

L2.p4 Animals as Consumers *(prerequisite)*

All animals, including humans, are consumers; they obtain food by eating other organisms or their products. Consumers break down the structures of the organisms they eat to obtain the materials they need to grow and function. Decomposers, including bacteria and fungi, use dead organisms or their products for food. *(prerequisite)*

L2.p4A Classify different organisms based on how they obtain energy for growth and development. *(prerequisite)*

L2.p4B Explain how an organism obtains energy from the food it consumes. *(prerequisite)*

L2.p5 Common Elements *(prerequisite)*

Living systems are made of complex molecules that consist mostly of a few elements, especially carbon, hydrogen, oxygen, nitrogen, and phosphorous. *(prerequisite)*

L2.p5A Recognize the six most common elements in organic molecules (C, H, N, O, P, S). *(prerequisite)*

L2.p5B Identify the most common complex molecules that make up living organisms. *(prerequisite)*

L2.p5C Predict what would happen if essential elements were withheld from developing cells. *(prerequisite)*

B2.1 Transformation of Matter and Energy in Cells

In multicellular organisms, cells are specialized to carry out specific functions such as transport, reproduction, or energy transformation.

B2.1A Explain how cells transform energy (ultimately obtained from the sun) from one form to another through the processes of photosynthesis and respiration. Identify the reactants and products in the general reaction of photosynthesis.

B2.1B Compare and contrast the transformation of matter and energy during photosynthesis and respiration.

B2.1C Explain cell division, growth, and development as a consequence of an increase in cell number, cell size, and/or cell products.

B2.1x Cell Differentiation

Following fertilization, cell division produces a small cluster of cells that then differentiate by appearance and function to form the basic tissues of an embryo.

B2.1d Describe how, through cell division, cells can become specialized for specific function.

B2.1e Predict what would happen if the cells from one part of a developing embryo were transplanted to another part of the embryo.

B2.2 Organic Molecules

There are four major categories of organic molecules that make up living systems: carbohydrates, fats, proteins, and nucleic acids.

B2.2A Explain how carbon can join to other carbon atoms in chains and rings to form large and complex molecules.

B2.2B Recognize the six most common elements in organic molecules (C, H, N, O, P, S).

B2.2C Describe the composition of the four major categories of organic molecules (carbohydrates, lipids, proteins, and nucleic acids).

B2.2D Explain the general structure and primary functions of the major complex organic molecules that compose living organisms.

B2.2E Describe how dehydration and hydrolysis relate to organic molecules.

B2.2x Proteins

Protein molecules are long, usually folded chains composed mostly of amino acids and are made of C, H, O, and N. Protein molecules assemble fats and carbohydrates; they function as enzymes, structural components, and hormones. The function of each protein molecule depends on its specific sequence of amino acids and the shape of the molecule.

B2.2f Explain the role of enzymes and other proteins in biochemical functions (e.g., the protein hemoglobin carries oxygen in some organisms, digestive enzymes, and hormones).

B2.2g Propose how moving an organism to a new environment may influence its ability to survive and predict the possible impact of this type of transfer.

B2.3 Maintaining Environmental Stability

The internal environment of living things must remain relatively constant. Many systems work together to maintain stability. Stability is challenged by changing physical, chemical, and environmental conditions as well as the presence of disease agents.

B2.3A Describe how cells function in a narrow range of physical conditions, such as temperature and pH (acidity), to perform life functions.

B2.3B Describe how the maintenance of a relatively stable internal environment is required for the continuation of life.

B2.3C Explain how stability is challenged by changing physical, chemical, and environmental conditions as well as the presence of disease agents.

B2.3x Homeostasis

The internal environment of living things must remain relatively constant. Many systems work together to maintain homeostasis. When homeostasis is lost, death occurs.

B2.3d Identify the general functions of the major systems of the human body (digestion, respiration, reproduction, circulation, excretion, protection from disease, and movement, control, and coordination) and describe ways that these systems interact with each other.

B2.3e Describe how human body systems maintain relatively constant internal conditions (temperature, acidity, and blood sugar).

B2.3f Explain how human organ systems help maintain human health.

B2.3g Compare the structure and function of a human body system or subsystem to a nonliving system (e.g., human joints to hinges, enzyme and substrate to interlocking puzzle pieces).

B2.4 Cell Specialization

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.

B2.4A Explain that living things can be classified based on structural, embryological, and molecular (relatedness of DNA sequence) evidence.

B2.4B Describe how various organisms have developed different specializations to accomplish a particular function and yet the end result is the same (e.g., excreting nitrogenous wastes in animals, obtaining oxygen for respiration).

B2.4C Explain how different organisms accomplish the same result using different structural specializations (gills vs. lungs vs. membranes).

B2.4d Analyze the relationships among organisms based on their shared physical, biochemical, genetic, and cellular characteristics and functional processes.

B2.4e Explain how cellular respiration is important for the production of ATP (build on aerobic vs. anaerobic).

B2.4f Recognize and describe that both living and nonliving things are composed of compounds, which are themselves made up of elements joined by energy-containing bonds, such as those in ATP.

B2.4g Explain that some structures in the modern eukaryotic cell developed from early prokaryotes, such as mitochondria, and in plants, chloroplasts.

B2.4h Describe the structures of viruses and bacteria.

B2.4i Recognize that while viruses lack cellular structure, they have the genetic material to invade living cells.

B2.5 Living Organism Composition

All living or once-living organisms are composed of carbohydrates, lipids, proteins, and nucleic acids. Carbohydrates and lipids contain many carbon-hydrogen bonds that also store energy.

B2.5A Recognize and explain that macromolecules such as lipids contain high energy bonds.

B2.5B Explain how major systems and processes work together in animals and plants, including relationships between organelles, cells, tissues, organs, organ systems, and organisms. Relate these to molecular functions.

B2.5C Describe how energy is transferred and transformed from the Sun to energy-rich molecules during photosynthesis.

B2.5D Describe how individual cells break down energy-rich molecules to provide energy for cell functions.

B2.5x Energy Transfer

All living or once living organisms are composed of carbohydrates, lipids, proteins, and nucleic acids. Carbohydrates and lipids contain many carbon-hydrogen bonds that also store energy. However, that energy must be transferred to ATP (adenosine triphosphate) to be usable by the cell.

B2.5e Explain the interrelated nature of photosynthesis and cellular respiration in terms of ATP synthesis and degradation.

B2.5f Relate plant structures and functions to the process of photosynthesis and respiration.

B2.5g Compare and contrast plant and animal cells.

B2.5h Explain the role of cell membranes as a highly selective barrier (diffusion, osmosis, and active transport).

B2.5i Relate cell parts/organelles to their function.

B2.6x Internal/External Cell Regulation

Cellular processes are regulated both internally and externally by environments in which cells exist, including local environments that lead to cell differentiation during the development of multicellular organisms. During the development of complex multicellular organisms, cell differentiation is regulated through the expression of different genes.

B2.6a Explain that the regulatory and behavioral responses of an organism to external stimuli occur in order to maintain both short- and long-term equilibrium.

B2.r6b Explain that complex interactions among the different kinds of molecules in the cell cause distinct cycles of activities, such as growth and division. Note that cell behavior can also be affected by molecules from other parts of the organism, such as hormones. *(recommended)*

B2.r6c Recognize and explain that communication and/or interaction are required between cells to coordinate their diverse activities. *(recommended)*

B2.r6d Explain how higher levels of organization result from specific complex interactions of smaller units and that their maintenance requires a constant input of energy as well as new material. *(recommended)*

B2.r6e Analyze the body's response to medical interventions such as organ transplants, medicines, and inoculations. *(recommended)*

STANDARD B3: INTERDEPENDENCE OF LIVING SYSTEMS AND THE ENVIRONMENT

Students describe the processes of photosynthesis and cellular respiration and how energy is transferred through food webs. They recognize and analyze the consequences of the dependence of organisms on environmental resources and the interdependence of organisms in ecosystems.

L3.p1 Populations, Communities, and Ecosystems *(prerequisite)*

Organisms of one species form a population. Populations of different organisms interact and form communities. Living communities and the nonliving factors that interact with them form ecosystems. *(prerequisite)*

L3.p1A Provide examples of a population, community, and ecosystem. *(prerequisite)*

L3.p2 Relationships Among Organisms *(prerequisite)*

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. Or one organism 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. *(prerequisite)*

L3.p2A Describe common relationships among organisms and provide examples of producer/consumer, predator/prey, or parasite/host relationship. *(prerequisite)*

L3.p2B Describe common ecological relationships between and among species and their environments (competition, territory, carrying capacity, natural balance, population, dependence, survival, and other biotic and abiotic factors). *(prerequisite)*

L3.p2C Describe the role of decomposers in the transfer of energy in an ecosystem. *(prerequisite)*

L3.p2D Explain how two organisms can be mutually beneficial and how that can lead to interdependency. *(prerequisite)*

L3.p3 Factors Influencing Ecosystems *(prerequisite)*

The number of organisms and populations an ecosystem can support depends on the biotic resources available and abiotic factors, such as quantity of light and water, range of temperatures, and soil composition. *(prerequisite)*

L3.p3A Identify the factors in an ecosystem that influence fluctuations in population size. *(prerequisite)*

L3.p3B Distinguish between the living (biotic) and nonliving (abiotic) components of an ecosystem. *(prerequisite)*

L3.p3C Explain how biotic and abiotic factors cycle in an ecosystem (water, carbon, oxygen, and nitrogen). *(prerequisite)*

L3.p3D Predict how changes in one population might affect other populations based upon their relationships in a food web. *(prerequisite)*

L3.p4 Human Impact on Ecosystems *(prerequisite)*

All organisms cause changes in their environments. Some of these changes are detrimental, whereas others are beneficial. *(prerequisite)*

L3.p4A Recognize that, and describe how, human beings are part of Earth's ecosystems. Note that human activities can deliberately or inadvertently alter the equilibrium in ecosystems. *(prerequisite)*

B3.1 Photosynthesis and Respiration

Organisms acquire their energy directly or indirectly from sunlight. Plants capture the Sun's energy and use it to convert carbon dioxide and water to sugar and oxygen through the process of photosynthesis. Through the process of cellular respiration, animals are able to release the energy stored in the molecules produced by plants and use it for cellular processes, producing carbon dioxide and water.

B3.1A Describe how organisms acquire energy directly or indirectly from sunlight.

B3.1B Illustrate and describe the energy conversions that occur during photosynthesis and respiration.

B3.1C Recognize the equations for photosynthesis and respiration and identify the reactants and products for both.

B3.1D Explain how living organisms gain and use mass through the processes of photosynthesis and respiration.

B3.1e Write the chemical equation for photosynthesis and cellular respiration and explain in words what they mean.

B3.1f Summarize the process of photosynthesis.

B3.2 Ecosystems

The chemical elements that make up the molecules of living things pass through food webs and are combined and recombined in different ways. At each link in an ecosystem, some energy is stored in newly made structures, but much is dissipated into the environment as heat. Continual input of energy from sunlight keeps the process going.

B3.2A Identify how energy is stored in an ecosystem.

B3.2B Describe energy transfer through an ecosystem, accounting for energy lost to the environment as heat.

B3.2C Draw the flow of energy through an ecosystem. Predict changes in the food web when one or more organisms are removed.

B3.3 Element Recombination

As matter cycles and energy flows through different levels of organization of living systems—cells, organs, organisms, and communities—and between living systems and the physical environment, chemical elements are recombined in different ways. Each recombination results in storage and dissipation of energy into the environment as heat. Matter and energy are conserved in each change.

B3.3A Use a food web to identify and distinguish producers, consumers, and decomposers and explain the transfer of energy through trophic levels.

B3.3b Describe environmental processes (e.g., the carbon and nitrogen cycles) and their role in processing matter crucial for sustaining life.

B3.4 Changes in Ecosystems

Although the interrelationships and interdependence of organisms may generate biological communities in ecosystems that are stable for hundreds or thousands of years, ecosystems always change when climate changes or when one or more new species appear as a result of migration or local evolution. The impact of the human species has major consequences for other species.

B3.4A Describe ecosystem stability. Understand that if a disaster such as flood or fire occurs, the damaged ecosystem is likely to recover in stages of succession that eventually result in a system similar to the original one.

B3.4B Recognize and describe that a great diversity of species increases the chance that at least some living organisms will survive in the face of cataclysmic changes in the environment.

B3.4C Examine the negative impact of human activities.

B3.4x Human Impact

Humans can have tremendous impact on the environment. Sometimes their impact is beneficial, and sometimes it is detrimental.

B3.4d Describe the greenhouse effect and list possible causes.

B3.4e List the possible causes and consequences of global warming.

B3.5 Populations

Populations of living things increase and decrease in size as they interact with other populations and with the environment. The rate of change is dependent upon relative birth and death rates.

B3.5A Graph changes in population growth, given a data table.

B3.5B Explain the influences that affect population growth.

B3.5C Predict the consequences of an invading organism on the survival of other organisms.

B3.5x Environmental Factors

The shape of population growth curves vary with the type of organism and environmental conditions, such as availability of nutrients and space. As the population increases and resources become more scarce, the population usually stabilizes at the carrying capacity of that environment.

B3.5d Describe different reproductive strategies employed by various organisms and explain their advantages and disadvantages.

B3.5e Recognize that and describe how the physical or chemical environment may influence the rate, extent, and nature of population dynamics within ecosystems.

B3.5f Graph an example of exponential growth. Then show the population leveling off at the carrying capacity of the environment.

B3.r5g Diagram and describe the stages of the life cycle for a human disease-causing organism. *(recommended)*

STANDARD B4: GENETICS

Students recognize that the specific genetic instructions for any organism are contained within genes composed of DNA molecules located in chromosomes. They explain the mechanism for the direct production of specific proteins based on inherited DNA. Students diagram how occasional modifications in genes and the random distribution of genes from each parent provide genetic variation and become the raw material for evolution. Content Statements, Performances, and Boundaries

L4.p1 Reproduction *(prerequisite)*

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. *(prerequisite)*

L4.p1A Compare and contrast the differences between sexual and asexual reproduction. *(prerequisite)*

L4.p1B Discuss the advantages and disadvantages of sexual vs. asexual reproduction. *(prerequisite)*

L4.p2 Heredity and Environment *(prerequisite)*

The characteristics of organisms are influenced by heredity and environment. For some characteristics, inheritance is more important. For other characteristics, interactions with the environment are more important. *(prerequisite)*

L4.p2A Explain that the traits of an individual are influenced by both the environment and the genetics of the individual. Acquired traits are not inherited; only genetic traits are inherited. *(prerequisite)*

B4.1 Genetics and Inherited Traits

Hereditary information is contained in genes, located in the chromosomes of each cell. Cells contain many thousands of different genes. One or many genes can determine an inherited trait of an individual, and a single gene can influence more than one trait. Before a cell divides, this genetic information must be copied and apportioned evenly into the daughter cells.

B4.1A Draw and label a homologous chromosome pair with heterozygous alleles highlighting a particular gene location.

B4.1B Explain that the information passed from parents to offspring is transmitted by means of genes that are coded in DNA molecules. These genes contain the information for the production of proteins.

B4.1c Differentiate between dominant, recessive, codominant, polygenic, and sex-linked traits.

B4.1d Explain the genetic basis for Mendel's laws of segregation and independent assortment.

B4.1e Determine the genotype and phenotype of monohybrid crosses using a Punnett Square.

B4.2 DNA

The genetic information encoded in DNA molecules provides instructions for assembling protein molecules. Genes are segments of DNA molecules. Inserting, deleting, or substituting DNA segments can alter genes. An altered gene may be passed on to every cell that develops from it. The resulting features may help, harm, or have little or no effect on the offspring's success in its environment.

B4.2A Show that when mutations occur in sex cells, they can be passed on to offspring (inherited mutations), but if they occur in other cells, they can be passed on to descendant cells only (noninherited mutations).

B4.2B Recognize that every species has its own characteristic DNA sequence.

B4.2C Describe the structure and function of DNA.

B4.2D Predict the consequences that changes in the DNA composition of particular genes may have on an organism (e.g., sickle cell anemia, other).

B4.2E Propose possible effects (on the genes) of exposing an organism to radiation and toxic chemicals.

B4.2x DNA, RNA, and Protein Synthesis

Protein synthesis begins with the information in a sequence of DNA bases being copied onto messenger RNA. This molecule moves from the nucleus to the ribosome in the cytoplasm where it is "read." Transfer RNA brings amino acids to the ribosome, where they are connected in the correct sequence to form a specific protein.

B4.2f Demonstrate how the genetic information in DNA molecules provides instructions for assembling protein molecules and that this is virtually the same mechanism for all life forms.

B4.2g Describe the processes of replication, transcription, and translation and how they relate to each other in molecular biology.

B4.2h Recognize that genetic engineering techniques provide great potential and responsibilities.

B4.r2i Explain how recombinant DNA technology allows scientists to analyze the structure and function of genes. *(recommended)*

B4.3 Cell Division — Mitosis and Meiosis

Sorting and recombination of genes in sexual reproduction results in a great variety of possible gene combinations from the offspring of any two parents.

B4.3A Compare and contrast the processes of cell division (mitosis and meiosis), particularly as those processes relate to production of new cells and to passing on genetic information between generations.

B4.3B Explain why only mutations occurring in gametes (sex cells) can be passed on to offspring.

B4.3C Explain how it might be possible to identify genetic defects from just a karyotype of a few cells.

B4.3d Explain that the sorting and recombination of genes in sexual reproduction result in a great variety of possible gene combinations from the offspring of two parents.

B4.3e Recognize that genetic variation can occur from such processes as crossing over, jumping genes, and deletion and duplication of genes.

B4.3f Predict how mutations may be transferred to progeny.

B4.3g Explain that cellular differentiation results from gene expression and/or environmental influence (e.g., metamorphosis, nutrition).

B4.4x Genetic Variation

Genetic variation is essential to biodiversity and the stability of a population. Genetic variation is ensured by the formation of gametes and their combination to form a zygote. Opportunities for genetic variation also occur during cell division when chromosomes exchange genetic material causing permanent changes in the DNA sequences of the chromosomes. Random mutations in DNA structure caused by the environment are another source of genetic variation.

B4.4a Describe how inserting, deleting, or substituting DNA segments can alter a gene. Recognize that an altered gene may be passed on to every cell that develops from it and that the resulting features may help, harm, or have little or no effect on the offspring's success in its environment.

B4.4b Explain that gene mutation in a cell can result in uncontrolled cell division called cancer. Also know that exposure of cells to certain chemicals and radiation increases mutations and thus increases the chance of cancer.

B4.4c Explain how mutations in the DNA sequence of a gene may be silent or result in phenotypic change in an organism and in its offspring.

B4.r5x Recombinant DNA

Recombinant DNA technology allows scientists in the laboratory to combine the genes from different sources, sometimes different species, into a single DNA molecule. This manipulation of genes using bacterial plasmids has been used for many practical purposes including the mass production of chemicals and drugs. *(recommended)*

B4.r5a Explain how recombinant DNA technology allows scientists to analyze the structure and function of genes. *(recommended)*

B4.r5b Evaluate the advantages and disadvantages of human manipulation of DNA. *(recommended)*

STANDARD B5: EVOLUTION AND BIODIVERSITY

Students recognize that evolution is the result of genetic changes that occur in constantly changing environments. They can explain that modern evolution includes both the concepts of common descent and natural selection. They illustrate how the consequences of natural selection and differential reproduction have led to the great biodiversity on Earth.

L5.p1 Survival and Extinction *(prerequisite)*

Individual organisms with certain traits in particular environments are more likely than others to survive and have offspring. When an environment changes, the advantage or disadvantage of characteristics can change. Extinction of a species occurs when the environment changes and the characteristics of a species are insufficient to allow survival. Fossils indicate that many organisms that lived long ago are extinct. Extinction of species is common; most of the species that have lived on the Earth no longer exist. *(prerequisite)*

L5.p1A Define a species and give examples. *(prerequisite)*

L5.p1B Define a population and identify local populations. *(prerequisite)*

L5.p1C Explain how extinction removes genes from the gene pool. *(prerequisite)*

L5.p1D Explain the importance of the fossil record. *(prerequisite)*

L5.p2 Classification *(prerequisite)*

Similarities among organisms are found in anatomical features, which can be used to infer the degree of relatedness among organisms. In classifying organisms, biologists consider details of internal and external structures to be more important than behavior or general appearance. *(prerequisite)*

L5.p2A Explain, with examples, that ecology studies the varieties and interactions of living things across space while evolution studies the varieties and interactions of living things across time. *(prerequisite)*

B5.1 Theory of Evolution

The theory of evolution provides a scientific explanation for the history of life on Earth as depicted in the fossil record and in the similarities evident within the diversity of existing organisms.

B5.1A Summarize the major concepts of natural selection (differential survival and reproduction of chance inherited variants, depending on environmental conditions).

B5.1B Describe how natural selection provides a mechanism for evolution.

B5.1c Summarize the relationships between present-day organisms and those that inhabited the Earth in the past (e.g., use fossil record, embryonic stages, homologous structures, chemical basis).

B5.1d Explain how a new species or variety originates through the evolutionary process of natural selection.

B5.1e Explain how natural selection leads to organisms that are well suited for the environment (differential survival and reproduction of chance inherited variants, depending upon environmental conditions).

B5.1f Explain, using examples, how the fossil record, comparative anatomy, and other evidence supports the theory of evolution.

B5.1g Illustrate how genetic variation is preserved or eliminated from a population through natural selection (evolution) resulting in biodiversity.

B5.2x Molecular Evidence

Molecular evidence substantiates the anatomical evidence for evolution and provides additional detail about the sequence in which various lines of descents branched.

B5.2a Describe species as reproductively distinct groups of organisms that can be classified based on morphological, behavioral, and molecular similarities.

B5.2b Explain that the degree of kinship between organisms or species can be estimated from the similarity of their DNA and protein sequences.

B5.2c Trace the relationship between environmental changes and changes in the gene pool, such as genetic drift and isolation of subpopulations.

B5.r2d Interpret a cladogram or phylogenetic tree showing evolutionary relationships among organisms. *(recommended)*

B5.3 Natural Selection

Evolution is the consequence of natural selection, the interactions of (1) the potential for a population to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, and (4) the ensuing selection from environmental pressure of those organisms better able to survive and leave offspring.

B5.3A Explain how natural selection acts on individuals, but it is populations that evolve. Relate genetic mutations and genetic variety produced by sexual reproduction to diversity within a given population.

B5.3B Describe the role of geographic isolation in speciation.

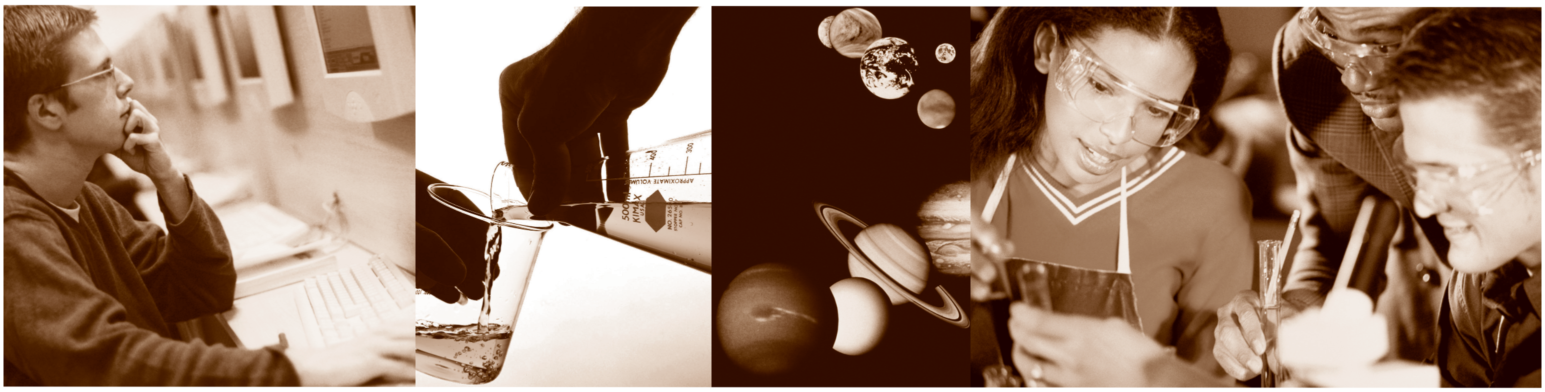
B4.3C Give examples of ways in which genetic variation and environmental factors are causes of evolution and the diversity of organisms.

B5.3d Explain how evolution through natural selection can result in changes in biodiversity.

B5.3e Explain how changes at the gene level are the foundation for changes in populations and eventually the formation of new species.

B5.3f Demonstrate and explain how biotechnology can improve a population and species.

High School Content Expectations



SCIENCE

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

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10/06

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Flint Schools

Joseph Grigas
Lake Fenton High School

Cheryl Hach
Kalamazoo Math Science Center

Ardis Herrold
Grosse Pointe North High School

Alberto de la Iglesia
Howell High School

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Macomb ISD

Shawn McNamara
Grosse Pointe South High School

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

Why Develop Content Standards and Expectations for High School?

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

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

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

An Overview

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

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

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

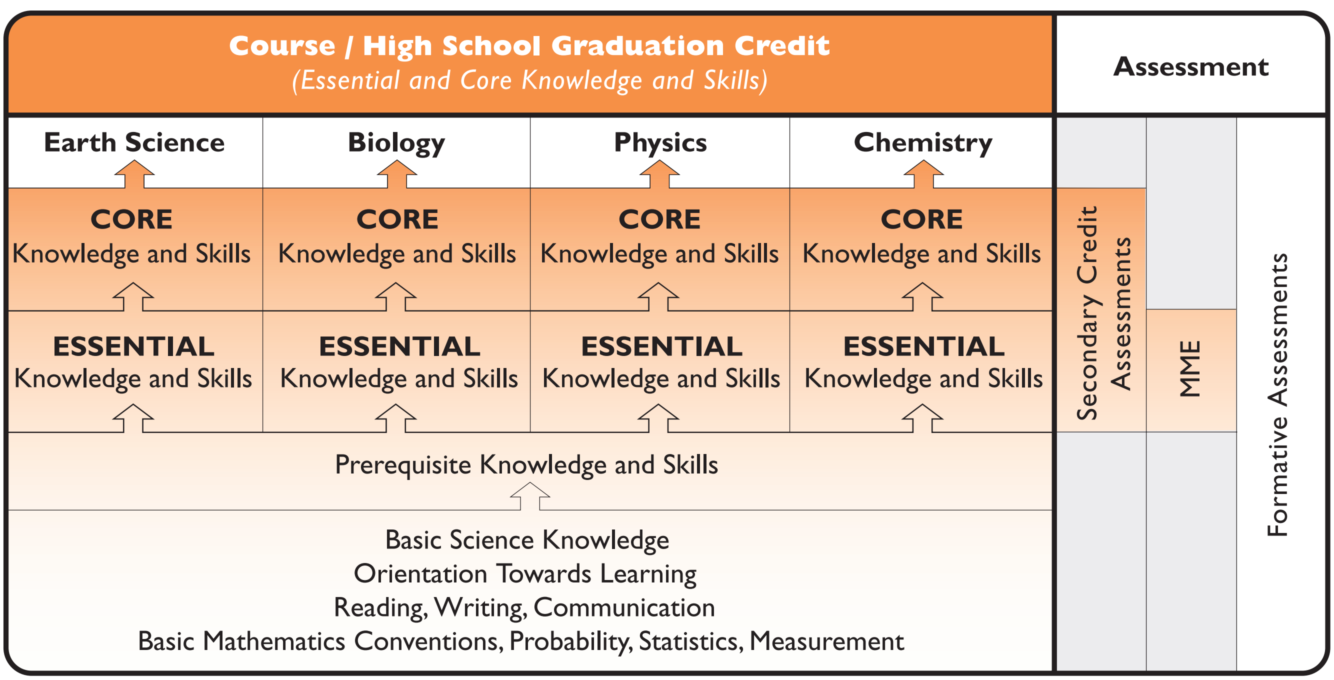
Useful and Connected Knowledge for All Students

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

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

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

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



Preparing Students for Successful Post-Secondary Engagement

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

Successful Post-Secondary Engagement

Practices of Science Literacy

Communicate accurately and effectively...

Identifying Science Principles

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

Using Science Principles

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

Scientific Inquiry

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

Reflection and Social Implications

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

State / National Landscape

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

State / Federal Expectations

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

Michigan High School Science Content Standards and Expectations

Earth Science

Biology

Physics

Chemistry

Models for District Alignment / Mapping

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

Other MI Documents / Programs

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

K-8 Educational Experience

Content Knowledge

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

Learning Processes

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

This chart includes talking points for professional development.

Practices of Science Literacy

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

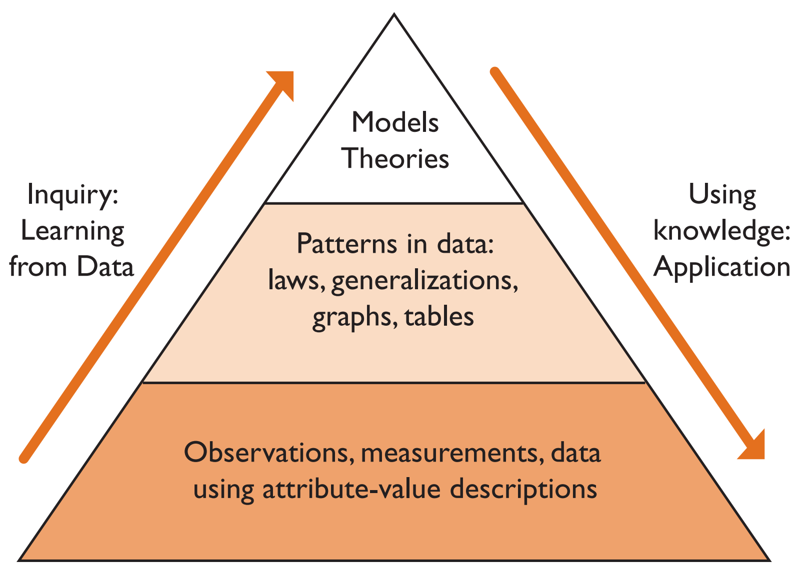


Figure 1: Knowledge and practices of model-based reasoning

Identifying Science Principles

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

Identifying Science Principles comprises the following general types of practices:

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

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

Using Science Principles

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

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

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

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

Scientific Inquiry

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

Scientific Inquiry comprises the following general types of performance expectations:

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

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

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

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

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

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

Scientific Reflection and Social Implications

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

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

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

Organization of the Expectations

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

Disciplines

Earth Science, Biology, Physics, and Chemistry

Organization of Each Standard

Each standard includes three parts:

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

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

Standard Statement

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

Content Statements

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

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

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

Performance Expectations

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

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

Michigan High School Science

CHEMISTRY

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

C E • **R I G O R** • R E L E V A N C E • R E L A T I O N S H I P S • R I G O R • R E
I P S • R E L A T I O N S H I P S • R I G O R • **R E L E V A N C E** • R E L A T
C E • R I G O R • R E L E V A N C E • R E L A T I O N S H I P S • R I G O R • R E
I P S • **R E L A T I O N S H I P S** • R I G O R • R E L E V A N C E • R E L A T

MICHIGAN Department of Education
10/06

CHEMISTRY (C)

Properties of matter

All objects and substances in the natural world are composed of matter. All matter has two fundamental properties: matter takes up space, and matter has intertia – it changes motion only when under the influence of a non-zero net force. Matter can be characterized in terms of its physical and chemical properties. These properties can be explained through the particulate model of matter, which describes the particles as atoms or molecules that are continuously in motion. The extent of the motion can be used to explain the physical properties associated with the common states of matter, solid, liquid and gas, as well as the changes of state. Whether or not a particular substance will exist as a solid, liquid or a gas will depend on the force due to particle motion in comparison to the force of attraction between particles. The attractive forces between particles are explained by the detailed structure of molecules and the atoms that compose them.

The structure of an atom in terms of its component protons, neutrons and electrons provides the basis for a systematic description of the building blocks of matter and their organization in the Periodic Table of the Elements. The Periodic Table demonstrates the relationship between the number of protons in an element, which is the defining characteristic of each element, and the chemical and physical properties of the elements. The Periodic Table also provides a structure for inquiry into the characteristics of the elements, since the electronic structure of atoms is reflected in the arrangement of elements in the Periodic Table. It is the electronic structure of atoms, especially the outermost electrons, that explains the chemical properties of elements and the breaking and making of bonds between atoms in a chemical reaction. An understanding of the bonding between elements leads to the concept of molecules as particles with specific combinations of atoms. When a substance consists of only one type of molecule it is referred to as a compound, with each compound having unique chemical and physical pr operties due to the detailed structure of its component molecules.

Changes in matter

As a general principle, a great deal of understanding chemistry is in differentiating what Nobelist Roald Hoffmann deftly labeled as "the same and not the same." Chemistry is filled with comparisons that fall under this rubric. Isomerism, for instance, is built on this idea. Molecules have the same molecular formula, but have completely different properties (ethyl acetate and butyric acid). In photo- or thermal isomerization reactions, what constitutes the starting material and the product different on the basis of some observable property because here, too, the molecular formulas are the same. We create false dichotomies for the convenience of categorization (physical properties versus chemical properties, ionic versus covalent bonding), yet when you dissolve blue cobalt chloride in water, and the solution turns pick, it is hard to argue "dissolving is a simple act of physical change."

Are polymorphous crystalline forms that different? There are real property differences that we would traditionally include as "chemical" changes (spectroscopic differences, for instance). Is dissolving sodium chloride in water and then evaporating the water to get it back that different? Not really. Ionic networks or lattices are complex structures with billions and billions of degenerate isomeric forms. Add a sample of radio-labeled sodium chloride to a differently-labeled sample; crystallization accomplishes a cross-over experiment no matter how you look at it.

Changes in matter then, are not simple binary classifications, but derived from defining what is changing and the criteria by which those changes are judged, particularly those properties that are used to make the decision about what sort of change has taken place. A useful concept that helps sort through these relationships is "material kind," a term that us used when a substance is made up of a homogenous aggregate of atomic or molecular species (macroscopic "liquid water" is a "material kind," and differentiates it from the matter – molecular water: "HOH" – that comprises it). Solid water and liquid water are different material kinds, while the matter that makes them up is the same.

Forms of energy

From the chemical perspective it is critical that the student understand the role of energy in the breaking and formation of chemical bonds, since bond breaking/making is the fundamental process in a chemical reaction. Potential energy is stored energy resulting from the attraction between two objects. Students commonly only understand gravitational potential energy. Just as the force of gravity results in potential energy changes as objects are moved relative to the earth, there are changes in potential energy when any particles held by a force (gravitational, electrical, magnetic, strong) are moved relative to each other. Chemical bonds are the result of a decrease in potential energy from the increased electrostatic attractions between atoms. Chemical bonds will not form unless there is a decrease in potential energy compared to the unbonded state. The strength of a chemical bond is directly proportional to the energy released when the bond forms from the separated gaseous atoms (ions). Breaking a chemical bond always requires energy to overcome the attractive forces holding the particle (ions, atoms, molecules) together. At grade 8 the student should be able to describe physical changes (changes of state, dissolving) in terms of rearranging the atoms, molecules or ions). At grade 12 the student should be able to describe chemical changes in terms of bond making and bond breaking to demonstrate a deeper understanding of the term "chemical potential energy".

Energy transformations

The transfer of energy and the conservation of energy are of great explanatory and predictive value. Left on their own all systems will naturally move to a state of minimum energy and maximum randomness. Application of these two driving forces coupled with the conservation of matter and energy will allow students to explain and predict most chemical phenomena. Students will understand the tremendous energy released in nuclear reactions is a result of small amounts of matter being converted to energy.

Chemistry Content Statement Outline

STANDARD C1 Inquiry, Reflection, and Social Implications

- C1.1 Scientific Inquiry
- C1.2 Scientific Reflection and Social Implications

STANDARD C2 Forms of Energy

- P2.p1 Potential Energy *(prerequisite)*
- C2.1x Chemical Potential Energy
- C2.2 Molecules in Motion
- C2.2x Molecular Entropy
- C2.3x Breaking Chemical Bonds
- C2.4x Electron Movement
- C2.5x Nuclear Stability

STANDARD C3 Energy Transfer and Conservation

- P3.p1 Conservation of Energy *(prerequisite)*
- C3.1x Hess's Law
- P3.p2 Energy Transfer *(prerequisite)*
- C3.2x Enthalpy
- C3.3 Heating Impacts
- C3.3x Bond Energy
- C3.4 Endothermic and Exothermic Reactions
- C3.4x Enthalpy and Entropy
- C3.5x Mass Defect

STANDARD C4 Properties of Matter

- P4.p1 Kinetic Molecular Theory *(prerequisite)*
- P4.p2 Elements, Compounds, and Mixtures *(prerequisite)*

STANDARD C4 Properties of Matter (cont.)

- C4.1x Molecular and Empirical Formulae
- C4.2 Nomenclature
- C4.3 Properties of Substances
- C4.3x Solids
- C4.4x Molecular Polarity
- C4.5x Ideal Gas Law
- C4.6x Moles
- C4.7x Solutions
- C4.8 Atomic Structure
- C4.8x Electron Configuration
- C4.9 Periodic Table
- C4.9x Electron Energy Levels
- C4.10 Neutral Atoms, Ions, and Isotopes
- C4.10x Average Atomic Mass

STANDARD C5 Changes in Matter

- P5.p1 Conservation of Matter *(prerequisite)*
- C5.r1x Rates of Reactions *(recommended)*
- C5.2 Chemical Changes
- C5.2x Balancing Equations
- C5.3x Equilibrium
- C5.4 Phase Change/Diagrams
- C5.4x Changes of State
- C5.5 Chemical Bonds — Trends
- C5.5x Chemical Bonds
- C5.6x Reduction/Oxidation Reactions
- C5.7 Acids and Bases
- C5.7x Brønsted-Lowry
- C5.8 Carbon Chemistry

STANDARD C1: 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.

C1.1 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.

C1.1A Generate new questions that can be investigated in the laboratory or field.

C1.1B 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.

C1.1C 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).

C1.1D Identify patterns in data and relate them to theoretical models.

C1.1E Describe a reason for a given conclusion using evidence from an investigation.

C1.1f Predict what would happen if the variables, methods, or timing of an investigation were changed.

C1.1g Based on empirical evidence, explain and critique the reasoning used to draw a scientific conclusion or explanation

C1.1h Design and conduct a systematic scientific investigation that tests a hypothesis. Draw conclusions from data presented in charts or tables.

C1.1i Distinguish between scientific explanations that are regarded as current scientific consensus and the emerging questions that active researchers investigate.

C1.2 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.

C1.2A Critique whether or not specific questions can be answered through scientific investigations.

C1.2B Identify and critique arguments about personal or societal issues based on scientific evidence.

C1.2C Develop an understanding of a scientific concept by accessing information from multiple sources. Evaluate the scientific accuracy and significance of the information.

C1.2D Evaluate scientific explanations in a peer review process or discussion format.

C1.2E Evaluate the future career and occupational prospects of science fields.

C1.2f Critique solutions to problems, given criteria and scientific constraints.

C1.2g Identify scientific tradeoffs in design decisions and choose among alternative solutions.

C1.2h Describe the distinctions between scientific theories, laws, hypotheses, and observations.

C1.2i Explain the progression of ideas and explanations that lead to science theories that are part of the current scientific consensus or core knowledge.

C1.2j Apply science principles or scientific data to anticipate effects of technological design decisions.

C1.2k Analyze how science and society interact from a historical, political, economic, or social perspective.

STANDARD C2: FORMS OF ENERGY

Students recognize the many forms of energy and understand that energy is central to predicting and explaining how and why chemical reactions occur. The chemical topics of bonding, gas behavior, kinetics, enthalpy, entropy, free energy, and nuclear stability are addressed in this standard.

Chemistry students relate temperature to the average kinetic energy of the molecules and use the kinetic molecular theory to describe and explain the behavior of gases and the rates of chemical reactions. They understand nuclear stability in terms of reaching a state of minimum potential energy.

P2.p1 Potential Energy *(prerequisite)*

Three forms of potential energy are gravitational, elastic, and chemical. Objects can have elastic potential energy due to their compression or chemical potential energy due to the arrangement of the atoms. *(prerequisite)*

P2.p1A Describe energy changes associated with changes of state in terms of the arrangement and order of the atoms (molecules) in each state. *(prerequisite)*

P2.p1B Use the positions and arrangements of atoms and molecules in solid, liquid, and gas state to explain the need for an input of energy for melting and boiling and a release of energy in condensation and freezing. *(prerequisite)*

C2.1x Chemical Potential Energy

Potential energy is stored whenever work must be done to change the distance between two objects. The attraction between the two objects may be gravitational, electrostatic, magnetic, or strong force. Chemical potential energy is the result of electrostatic attractions between atoms.

C2.1a Explain the changes in potential energy (due to electrostatic interactions) as a chemical bond forms and use this to explain why bond breaking always requires energy.

C2.1b Describe energy changes associated with chemical reactions in terms of bonds broken and formed (including intermolecular forces).

C2.1c Compare qualitatively the energy changes associated with melting various types of solids in terms of the types of forces between the particles in the solid.

C2.2 Molecules in Motion

Molecules that compose matter are in constant motion (translational, rotational, vibrational). Energy may be transferred from one object to another during collisions between molecules.

C2.2A Describe conduction in terms of molecules bumping into each other to transfer energy. Explain why there is better conduction in solids and liquids than gases.

C2.2B Describe the various states of matter in terms of the motion and arrangement of the molecules (atoms) making up the substance.

C2.2x Molecular Entropy

As temperature increases, the average kinetic energy and the entropy of the molecules in a sample increases.

C2.2c Explain changes in pressure, volume, and temperature for gases using the kinetic molecular model.

C2.2d Explain convection and the difference in transfer of thermal energy for solids, liquids, and gases using evidence that molecules are in constant motion.

C2.2e Compare the entropy of solids, liquids, and gases.

C2.2f Compare the average kinetic energy of the molecules in a metal object and a wood object at room temperature.

C2.3x Breaking Chemical Bonds

For molecules to react, they must collide with enough energy (activation energy) to break old chemical bonds before their atoms can be rearranged to form new substances.

C2.3a Explain how the rate of a given chemical reaction is dependent on the temperature and the activation energy.

C2.3b Draw and analyze a diagram to show the activation energy for an exothermic reaction that is very slow at room temperature.

C2.4x Electron Movement

For each element, the arrangement of electrons surrounding the nucleus is unique. These electrons are found in different energy levels and can only move from a lower energy level (closer to nucleus) to a higher energy level (farther from nucleus) by absorbing energy in discrete packets. The energy content of the packets is directly proportional to the frequency of the radiation. These electron transitions will produce unique absorption spectra for each element. When the electron returns from an excited (high energy state) to a lower energy state, energy is emitted in only certain wavelengths of light, producing an emission spectra.

C2.4a Describe energy changes in flame tests of common elements in terms of the (characteristic) electron transitions.

C2.4b Contrast the mechanism of energy changes and the appearance of absorption and emission spectra.

C2.4c Explain why an atom can absorb only certain wavelengths of light.

C2.4d Compare various wavelengths of light (visible and nonvisible) in terms of frequency and relative energy.

C2.5x Nuclear Stability

Nuclear stability is related to a decrease in potential energy when the nucleus forms from protons and neutrons. If the neutron/proton ratio is unstable, the element will undergo radioactive decay. The rate of decay is characteristic of each isotope; the time for half the parent nuclei to decay is called the half-life. Comparison of the parent/daughter nuclei can be used to determine the age of a sample. Heavier elements are formed from the fusion of lighter elements in the stars.

C2.5a Determine the age of materials using the ratio of stable and unstable isotopes of a particular type.

C2.r5b Illustrate how elements can change in nuclear reactions using balanced equations. *(recommended)*

C2.r5c Describe the potential energy changes as two protons approach each other. *(recommended)*

C2.r5d Describe how and where all the elements on earth were formed. *(recommended)*

STANDARD C3: ENERGY TRANSFER AND CONSERVATION

Students apply the First and Second Laws of Thermodynamics to explain and predict most chemical phenomena.

Chemistry students use the term enthalpy to describe the transfer of energy between reactants and products in simple calorimetry experiments performed in class and will recognize Hess's Law as an application of the conservation of energy.

Students understand the tremendous energy released in nuclear reactions is a result of small amounts of matter being converted to energy.

P3.p1 Conservation of Energy *(prerequisite)*

When energy is transferred from one system to another, the quantity of energy before transfer equals the quantity of energy after transfer. *(prerequisite)*

P3.p1A Explain that the amount of energy necessary to heat a substance will be the same as the amount of energy released when the substance is cooled to the original temperature. *(prerequisite)*

C3.1x Hess's Law

For chemical reactions where the state and amounts of reactants and products are known, the amount of energy transferred will be the same regardless of the chemical pathway. This relationship is called Hess's law.

C3.1a Calculate the ΔH for a given reaction using Hess's Law.

C3.1b Draw enthalpy diagrams for exothermic and endothermic reactions.

C3.1c Calculate the ΔH for a chemical reaction using simple coffee cup calorimetry.

C3.1d Calculate the amount of heat produced for a given mass of reactant from a balanced chemical equation.

P3.p2 Energy Transfer *(prerequisite)*

Nuclear reactions take place in the sun. In plants, light from the sun is transferred to oxygen and carbon compounds, which, in combination, have chemical potential energy (photosynthesis). *(prerequisite)*

P3.p2A Trace (or diagram) energy transfers involving various types of energy including nuclear, chemical, electrical, sound, and light. *(prerequisite)*

C3.2x Enthalpy

Chemical reactions involve breaking bonds in reactants (endothermic) and forming new bonds in the products (exothermic). The enthalpy change for a chemical reaction will depend on the relative strengths of the bonds in the reactants and products.

C3.2a Describe the energy changes in photosynthesis and in the combustion of sugar in terms of bond breaking and bond making.

C3.2b Describe the relative strength of single, double, and triple covalent bonds between nitrogen atoms.

C3.3 Heating Impacts

Heating increases the kinetic (translational, rotational, and vibrational) energy of the atoms composing elements and the molecules or ions composing compounds. As the kinetic (translational) energy of the atoms, molecules, or ions increases, the temperature of the matter increases. Heating a sample of a crystalline solid increases the kinetic (vibrational) energy of the atoms, molecules, or ions. When the kinetic (vibrational) energy becomes great enough, the crystalline structure breaks down, and the solid melts.

C3.3A Describe how heat is conducted in a solid.

C3.3B Describe melting on a molecular level.

C3.3x Bond Energy

Chemical bonds possess potential (vibrational and rotational) energy.

C3.3c Explain why it is necessary for a molecule to absorb energy in order to break a chemical bond.

C3.4 Endothermic and Exothermic Reactions

Chemical interactions either release energy to the environment (exothermic) or absorb energy from the environment (endothermic).

C3.4A Use the terms endothermic and exothermic correctly to describe chemical reactions in the laboratory.

C3.4B Explain why chemical reactions will either release or absorb energy.

C3.4x Enthalpy and Entropy

All chemical reactions involve rearrangement of the atoms. In an exothermic reaction, the products have less energy than the reactants. There are two natural driving forces: (1) toward minimum energy (enthalpy) and (2) toward maximum disorder (entropy).

C3.4c Write chemical equations including the heat term as a part of equation or using ΔH notation.

C3.4d Draw enthalpy diagrams for reactants and products in endothermic and exothermic reactions.

C3.4e Predict if a chemical reaction is spontaneous given the enthalpy (ΔH) and entropy (ΔS) changes for the reaction using Gibb's Free Energy, $\Delta G = \Delta H - T\Delta S$ (Note: mathematical computation of ΔG is not required.)

C3.4f Explain why some endothermic reactions are spontaneous at room temperature.

C3.4g Explain why gases are less soluble in warm water than cold water.

C3.5x Mass Defect

Nuclear reactions involve energy changes many times the magnitude of chemical changes. In chemical reactions matter is conserved, but in nuclear reactions a small loss in mass (mass defect) will account for the tremendous release of energy. The energy released in nuclear reactions can be calculated from the mass defect using $E = mc^2$.

C3.5a Explain why matter is not conserved in nuclear reactions.

STANDARD C4: PROPERTIES OF MATTER

Compounds, elements, and mixtures are categories used to organize matter. Students organize materials into these categories based on their chemical and physical behavior. Students understand the structure of the atom to make predictions about the physical and chemical properties of various elements and the types of compounds those elements will form. An understanding of the organization the Periodic Table in terms of the outer electron configuration is one of the most important tools for the chemist and student to use in prediction and explanation of the structure and behavior of atoms.

P4.p1 Kinetic Molecular Theory *(prerequisite)*

Properties of solids, liquids, and gases are explained by a model of matter that is composed of tiny particles in motion. *(prerequisite)*

P4.p1A For a substance that can exist in all three phases, describe the relative motion of the particles in each of the phases. *(prerequisite)*

P4.p1B For a substance that can exist in all three phases, make a drawing that shows the arrangement and relative spacing of the particles in each of the phases. *(prerequisite)*

P4.p1C For a simple compound, present a drawing that shows the number of particles in the system does not change as a result of a phase change. *(prerequisite)*

P4.p2 Elements, Compounds, and Mixtures *(prerequisite)*

Elements are a class of substances composed of a single kind of atom. Compounds are composed of two or more different elements chemically combined. Mixtures are composed of two or more different elements and/or compounds physically combined. Each element and compound has physical and chemical properties, such as boiling point, density, color, and conductivity, which are independent of the amount of the sample. *(prerequisite)*

P4.p2A Distinguish between an element, compound, or mixture based on drawings or formulae. *(prerequisite)*

P4.p2B Identify a pure substance (element or compound) based on unique chemical and physical properties. *(prerequisite)*

P4.p2C Separate mixtures based on the differences in physical properties of the individual components. *(prerequisite)*

P4.p2D Recognize that the properties of a compound differ from those of its individual elements. *(prerequisite)*

C4.1x Molecular and Empirical Formulae

Compounds have a fixed percent elemental composition. For a compound, the empirical formula can be calculated from the percent composition or the mass of each element. To determine the molecular formula from the empirical formula, the molar mass of the substance must also be known.

C4.1a Calculate the percent by weight of each element in a compound based on the compound formula.

C4.1b Calculate the empirical formula of a compound based on the percent by weight of each element in the compound.

C4.1c Use the empirical formula and molecular weight of a compound to determine the molecular formula.

C4.2 Nomenclature

All compounds have unique names that are determined systematically.

C4.2A Name simple binary compounds using their formulae.

C4.2B Given the name, write the formula of simple binary compounds.

C4.2x Nomenclature

All molecular and ionic compounds have unique names that are determined systematically.

C4.2c Given a formula, name the compound.

C4.2d Given the name, write the formula of ionic and molecular compounds.

C4.2e Given the formula for a simple hydrocarbon, draw and name the isomers.

C4.3 Properties of Substances

Differences in the physical and chemical properties of substances are explained by the arrangement of the atoms, ions, or molecules of the substances and by the strength of the forces of attraction between the atoms, ions, or molecules.

C4.3A Recognize that substances that are solid at room temperature have stronger attractive forces than liquids at room temperature, which have stronger attractive forces than gases at room temperature.

C4.3B Recognize that solids have a more ordered, regular arrangement of their particles than liquids and that liquids are more ordered than gases.

C4.3x Solids

Solids can be classified as metallic, ionic, covalent, or network covalent. These different types of solids have different properties that depend on the particles and forces found in the solid.

C4.3c Compare the relative strengths of forces between molecules based on the melting point and boiling point of the substances.

C4.3d Compare the strength of the forces of attraction between molecules of different elements. (For example, at room temperature, chlorine is a gas and iodine is a solid.)

C4.3e Predict whether the forces of attraction in a solid are primarily metallic, covalent, network covalent, or ionic based upon the elements' location on the periodic table.

C4.3f Identify the elements necessary for hydrogen bonding (N, O, F).

C4.3g Given the structural formula of a compound, indicate all the intermolecular forces present (dispersion, dipolar, hydrogen bonding).

C4.3h Explain properties of various solids such as malleability, conductivity, and melting point in terms of the solid's structure and bonding.

C4.3i Explain why ionic solids have higher melting points than covalent solids. (For example, NaF has a melting point of 995°C, while water has a melting point of 0° C.)

C4.4x Molecular Polarity

The forces between molecules depend on the net polarity of the molecule as determined by shape of the molecule and the polarity of the bonds.

C4.4a Explain why at room temperature different compounds can exist in different phases.

C4.4b Identify if a molecule is polar or nonpolar given a structural formula for the compound.

C4.5x Ideal Gas Law

The forces in gases are explained by the ideal gas law.

C4.5a Provide macroscopic examples, atomic and molecular explanations, and mathematical representations (graphs and equations) for the pressure-volume relationship in gases.

C4.5b Provide macroscopic examples, atomic and molecular explanations, and mathematical representations (graphs and equations) for the pressure-temperature relationship in gases.

C4.5c Provide macroscopic examples, atomic and molecular explanations, and mathematical representations (graphs and equations) for the temperature-volume relationship in gases.

C4.6x Moles

The mole is the standard unit for counting atomic and molecular particles in terms of common mass units.

C4.6a Calculate the number of moles of any compound or element given the mass of the substance.

C4.6b Calculate the number of particles of any compound or element given the mass of the substance.

C4.7x Solutions

The physical properties of a solution are determined by the concentration of solute.

C4.7a Investigate the difference in the boiling point or freezing point of pure water and a salt solution.

C4.7b Compare the density of pure water to that of a sugar solution.

C4.8 Atomic Structure

Electrons, protons, and neutrons are parts of the atom and have measurable properties, including mass and, in the case of protons and electrons, charge. The nuclei of atoms are composed of protons and neutrons. A kind of force that is only evident at nuclear distances holds the particles of the nucleus together against the electrical repulsion between the protons.

C4.8A Identify the location, relative mass, and charge for electrons, protons, and neutrons.

C4.8B Describe the atom as mostly empty space with an extremely small, dense nucleus consisting of the protons and neutrons and an electron cloud surrounding the nucleus.

C4.8C Recognize that protons repel each other and that a strong force needs to be present to keep the nucleus intact.

C4.8D Give the number of electrons and protons present if the fluoride ion has a -1 charge.

C4.8x Electron Configuration

Electrons are arranged in main energy levels with sublevels that specify particular shapes and geometry. Orbitals represent a region of space in which an electron may be found with a high level of probability. Each defined orbital can hold two electrons, each with a specific spin orientation. The specific assignment of an electron to an orbital is determined by a set of 4 quantum numbers. Each element and, therefore, each position in the periodic table is defined by a unique set of quantum numbers.

C4.8e Write the complete electron configuration of elements in the first four rows of the periodic table.

C4.8f Write kernel structures for main group elements.

C4.8g Predict oxidation states and bonding capacity for main group elements using their electron structure.

C4.8h Describe the shape and orientation of s and p orbitals.

C4.8i Describe the fact that the electron location cannot be exactly determined at any given time.

C4.9 Periodic Table

In the periodic table, elements are arranged in order of increasing number of protons (called the atomic number). Vertical groups in the periodic table (families) have similar physical and chemical properties due to the same outer electron structures.

C4.9A Identify elements with similar chemical and physical properties using the periodic table.

C4.9x Electron Energy Levels

The rows in the periodic table represent the main electron energy levels of the atom. Within each main energy level are sublevels that represent an orbital shape and orientation.

C4.9b Identify metals, non-metals, and metalloids using the periodic table.

C4.9c Predict general trends in atomic radius, first ionization energy, and electonegativity of the elements using the periodic table.

C4.10 Neutral Atoms, Ions, and Isotopes

A neutral atom of any element will contain the same number of protons and electrons. Ions are charged particles with an unequal number of protons and electrons. Isotopes are atoms of the same element with different numbers of neutrons and essentially the same chemical and physical properties.

C4.10A List the number of protons, neutrons, and electrons for any given ion or isotope.

C4.10B Recognize that an element always contains the same number of protons.

C4.10x Average Atomic Mass

The atomic mass listed on the periodic table is an average mass for all the different isotopes that exist, taking into account the percent and mass of each different isotope.

C4.10c Calculate the average atomic mass of an element given the percent abundance and mass of the individual isotopes.

C4.10d Predict which isotope will have the greatest abundance given the possible isotopes for an element and the average atomic mass in the periodic table.

C4.10e Write the symbol for an isotope, ${}^{A}_{Z}X$, where Z is the atomic number, A is the mass number, and X is the symbol for the element.

STANDARD C5: CHANGES IN MATTER

Students will analyze a chemical change phenomenon from the point of view of what is the same and what is not the same.

P5.p1 Conservation of Matter *(prerequisite)*

Changes of state are explained by a model of matter composed of tiny particles that are in motion. When substances undergo changes of state, neither atoms nor molecules themselves are changed in structure. Mass is conserved when substances undergo changes of state. *(prerequisite)*

P5.p1A Draw a picture of the particles of an element or compound as a solid, liquid, and gas. *(prerequisite)*

C5.r1x Rates of Reactions *(recommended)*

The rate of a chemical reaction will depend upon (1) concentration of reacting species, (2) temperature of reaction, (3) pressure if reactants are gases, and (4) nature of the reactants. A model of matter composed of tiny particles that are in constant motion is used to explain rates of chemical reactions. *(recommended)*

C5.r1a Predict how the rate of a chemical reaction will be influenced by changes in concentration, and temperature, pressure. *(recommended)*

C5.r1b Explain how the rate of a reaction will depend on concentration, temperature, pressure, and nature of reactant. *(recommended)*

C5.2 Chemical Changes

Chemical changes can occur when two substances, elements, or compounds interact and produce one or more different substances whose physical and chemical properties are different from the interacting substances. When substances undergo chemical change, the number of atoms in the reactants is the same as the number of atoms in the products. This can be shown through simple balancing of chemical equations. Mass is conserved when substances undergo chemical change. The total mass of the interacting substances (reactants) is the same as the total mass of the substances produced (products).

C5.2A Balance simple chemical equations applying the conservation of matter.

C5.2B Distinguish between chemical and physical changes in terms of the properties of the reactants and products.

C5.2C Draw pictures to distinguish the relationships between atoms in physical and chemical changes.

C5.2x Balancing Equations

A balanced chemical equation will allow one to predict the amount of product formed.

C5.2d Calculate the mass of a particular compound formed from the masses of starting materials.

C5.2e Identify the limiting reagent when given the masses of more than one reactant.

C5.2f Predict volumes of product gases using initial volumes of gases at the same temperature and pressure.

C5.2g Calculate the number of atoms present in a given mass of element.

C5.3x Equilibrium

Most chemical reactions reach a state of dynamic equilibrium where the rates of the forward and reverse reactions are equal.

C5.3a Describe equilibrium shifts in a chemical system caused by changing conditions (Le Chatelier's Principle).

C5.3b Predict shifts in a chemical system caused by changing conditions (Le Chatelier's Principle).

C5.3c Predict the extent reactants are converted to products using the value of the equilibrium constant.

C5.4 Phase Change/Diagrams

Changes of state require a transfer of energy. Water has unusually high-energy changes associated with its changes of state.

C5.4A Compare the energy required to raise the temperature of one gram of aluminum and one gram of water the same number of degrees.

C5.4B Measure, plot, and interpret the graph of the temperature versus time of an ice-water mixture, under slow heating, through melting and boiling.

C5.4x Changes of State

All changes of state require energy. Changes in state that require energy involve breaking forces holding the particles together. The amount of energy will depend on the type of forces.

C5.4c Explain why both the melting point and boiling points for water are significantly higher than other small molecules of comparable mass (e.g., ammonia and methane).

C5.4d Explain why freezing is an exothermic change of state.

C5.4e Compare the melting point of covalent compounds based on the strength of IMFs (intermolecular forces).

C5.5 Chemical Bonds — Trends

An atom's electron configuration, particularly of the outermost electrons, determines how the atom can interact with other atoms. The interactions between atoms that hold them together in molecules or between oppositely charged ions are called chemical bonds.

C5.5A Predict if the bonding between two atoms of different elements will be primarily ionic or covalent.

C5.4B Predict the formula for binary compounds of main group elements.

C5.5x Chemical Bonds

Chemical bonds can be classified as ionic, covalent, and metallic. The properties of a compound depend on the types of bonds holding the atoms together.

C5.5c Draw Lewis structures for simple compounds.

C5.5d Compare the relative melting point, electrical and thermal conductivity and hardness for ionic, metallic, and covalent compounds.

C5.5e Relate the melting point, hardness, and electrical and thermal conductivity of a substance to its structure.

C5.6x Reduction/Oxidation Reactions

Chemical reactions are classified according to the fundamental molecular or submolecular changes that occur. Reactions that involve electron transfer are known as oxidation/reduction (or "redox").

C5.6a Balance half-reactions and describe them as oxidations or reductions.

C5.6b Predict single replacement reactions.

C5.6c Explain oxidation occurring when two different metals are in contact.

C5.6d Calculate the voltage for spontaneous redox reactions from the standard reduction potentials.

C5.6e Identify the reactions occurring at the anode and cathode in an electrochemical cell.

C5.7 Acids and Bases

Acids and bases are important classes of chemicals that are recognized by easily observed properties in the laboratory. Acids and bases will neutralize each other. Acid formulas usually begin with hydrogen, and base formulas are a metal with a hydroxide ion. As the pH decreases, a solution becomes more acidic. A difference of one pH unit is a factor of 10 in hydrogen ion concentration.

C5.7A Recognize formulas for common inorganic acids, carboxylic acids, and bases formed from families I and II.

C5.7B Predict products of an acid-base neutralization.

C5.7C Describe tests that can be used to distinguish an acid from a base.

C5.7D Classify various solutions as acidic or basic, given their pH.

C5.7E Explain why lakes with limestone or calcium carbonate experience less adverse effects from acid rain than lakes with granite beds.

C5.7x Brønsted-Lowry

Chemical reactions are classified according to the fundamental molecular or submolecular changes that occur. Reactions that involve proton transfer are known as acid/base reactions.

C5.7f Write balanced chemical equations for reactions between acids and bases and perform calculations with balanced equations.

C5.7g Calculate the pH from the hydronium ion or hydroxide ion concentration.

C5.7h Explain why sulfur oxides and nitrogen oxides contribute to acid rain.

C5.r7i Identify the Brønsted-Lowry conjugate acid-base pairs in an equation. *(recommended)*

C5.8 Carbon Chemistry

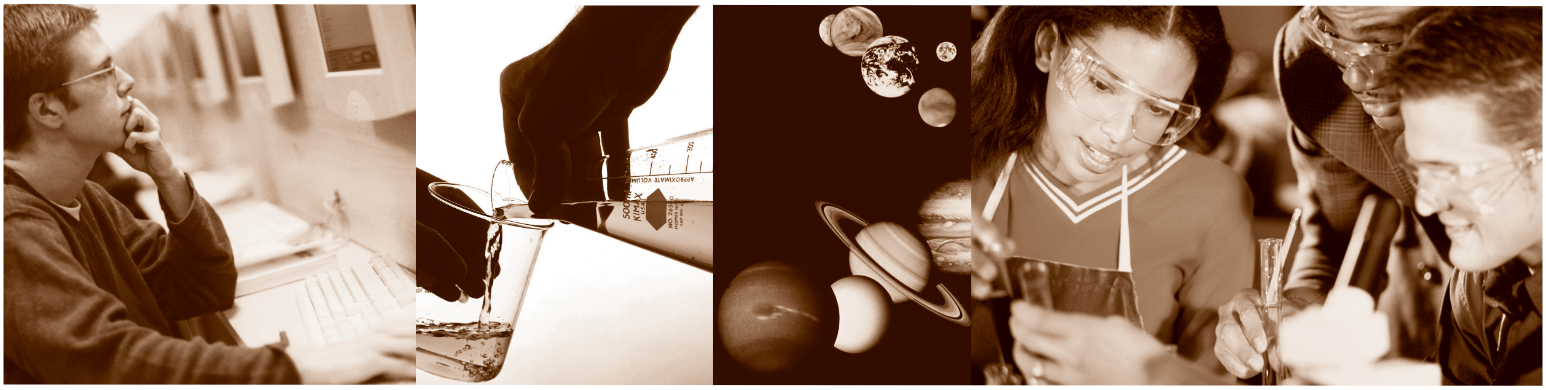
The chemistry of carbon is important. Carbon atoms can bond to one another in chains, rings, and branching networks to form a variety of structures, including synthetic polymers, oils, and the large molecules essential to life.

C5.8A Draw structural formulas for up to ten carbon chains of simple hydrocarbons.

C5.8B Draw isomers for simple hydrocarbons.

C5.8C Recognize that proteins, starches, and other large biological molecules are polymers.

High School Content Expectations



SCIENCE

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

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N C E • R I G O R • R E L E V A N C E • R E L A T I O N S H I P S • R I G O R • R E L E V A N
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10/06

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

Why Develop Content Standards and Expectations for High School?

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

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

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

An Overview

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

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

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

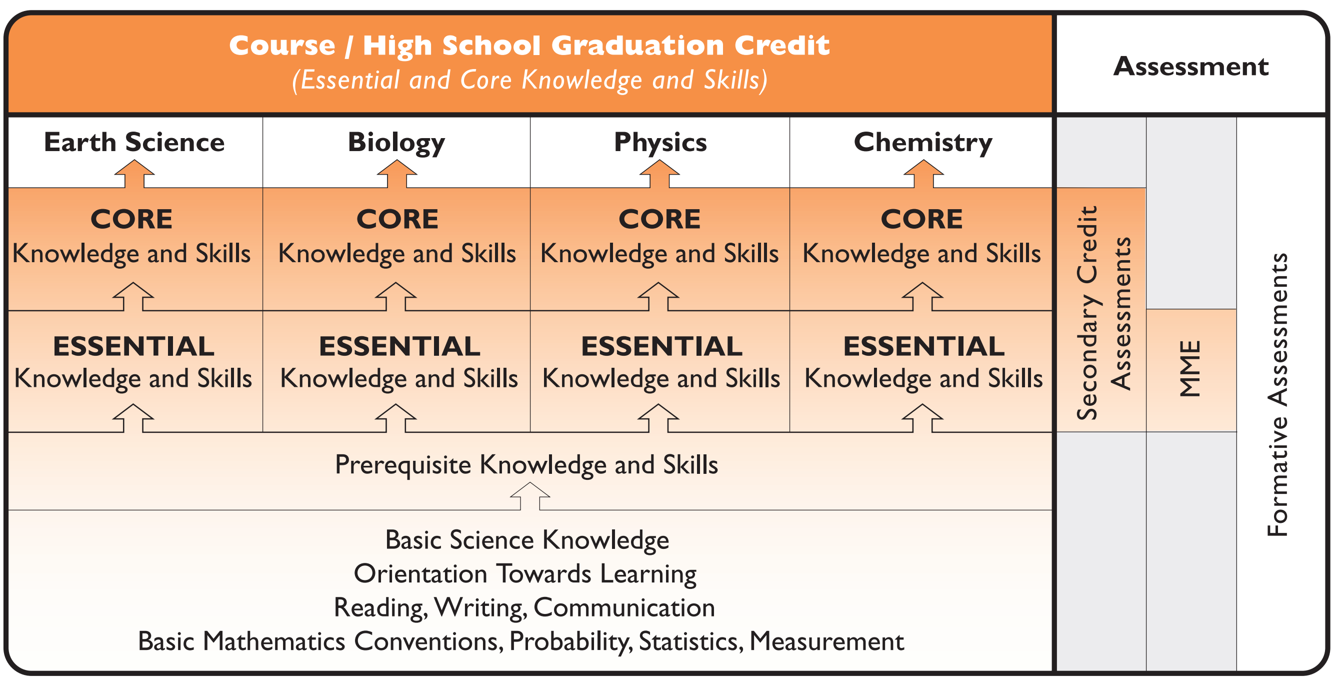
Useful and Connected Knowledge for All Students

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

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

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

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



Preparing Students for Successful Post-Secondary Engagement

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

Successful Post-Secondary Engagement

Practices of Science Literacy

Communicate accurately and effectively...

Identifying Science Principles

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

Using Science Principles

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

Scientific Inquiry

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

Reflection and Social Implications

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

State / National Landscape

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

State / Federal Expectations

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

Michigan High School Science Content Standards and Expectations

Earth Science

Biology

Physics

Chemistry

Models for District Alignment / Mapping

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

Other MI Documents / Programs

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

K-8 Educational Experience

Content Knowledge

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

Learning Processes

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

This chart includes talking points for professional development.

Practices of Science Literacy

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

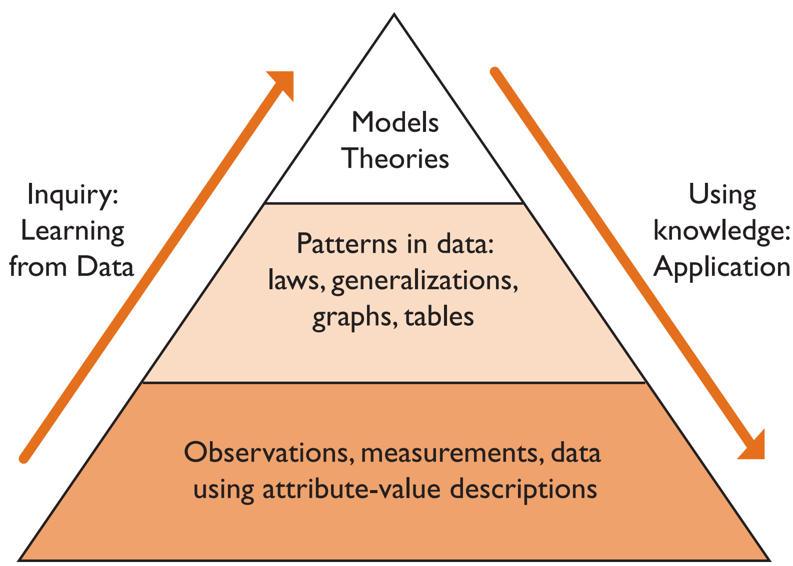


Figure 1: Knowledge and practices of model-based reasoning

Identifying Science Principles

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

Identifying Science Principles comprises the following general types of practices:

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

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

Using Science Principles

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

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

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

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

Scientific Inquiry

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

Scientific Inquiry comprises the following general types of performance expectations:

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

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

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

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

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

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

Scientific Reflection and Social Implications

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

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

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

Organization of the Expectations

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

Disciplines

Earth Science, Biology, Physics, and Chemistry

Organization of Each Standard

Each standard includes three parts:

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

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

Standard Statement

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

Content Statements

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

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

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

Performance Expectations

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

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

Michigan High School Science

PHYSICS

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

C E • R I G O R • R E L E V A N C E • R E L A T I O N S H I P S • R I G O R • R E
I P S • R E L A T I O N S H I P S • R I G O R • R E L E V A N C E • R E L A T
C E • R I G O R • R E L E V A N C E • R E L A T I O N S H I P S • R I G O R • R E
I P S • R E L A T I O N S H I P S • R I G O R • R E L E V A N C E • R E L A T

MICHIGAN Department of Education
10/06

PHYSICS (P)

Physics is a basic science. It is a human construct to attempt to explain observations on both the macro and micro levels. Knowledge of physical principles allows understanding in other sciences and everyday experiences, (e.g., heat exchanges in the atmosphere as they relate to weather; pressure and temperature differences causing different geological formations; radiation of electromagnetic energy and how it affects photosynthesis; the behavior of light and the eye; electricity, electromagnetic waves and your cell phone; nuclear fission and power plants; atomic structure and chemical reactions).

The universe is in a state of constant change. From small particles (electrons) to the large systems (galaxies) all things are in motion. Therefore, understanding the universe requires the ability to describe and represent various types of motion. Kinematics, the description of motion, always involves measurements of position and time. The relationships between these quantities can be represented by mathematical statements, graphs, and motion maps. These representations are powerful tools that can not only describe past motions but can also predict future events.

Objects can interact with each other by direct contact (e.g., pushes or pulls, friction) or at a distance (e.g., gravity, electromagnetism). Forces are used for describing interactions between objects. Non-zero net forces always cause changes in motion (Newton's first law). These changes can be changes in speed, direction, or both. Newton's second law summarizes relationships between net forces, masses, and changes in motion. Whenever one object exerts a force on another, a force equal in magnitude and opposite in direction is exerted back on it (Newton's third law).

Energy is a constant in an ever-changing world. Energy from the sun fuels electrical storms, hurricanes, tornados, and photosynthesis. In turn, the products of photosynthesis (carbohydrates and oxygen) react during respiration to fuel the life processes, such as growth and reproduction, of plants and animals. Energy is the conceptual system for explaining how the universe works and accounting for changes in matter. (NAEP) Energy is not a "thing". "Three energy-related ideas are important. One is energy transformation. All physical events involve transferring energy or changing one form of energy into another. … A second idea is the conservation of energy. … A third idea is that whenever there is a transformation of energy, some of it is likely to go into heat which is spread around and is therefore not available for use." (*Benchmarks for Science Literacy*, AAAS, 1993)

Physics Content Statement Outline

STANDARD P1 Inquiry, Reflection, and Social Implications

P1.1	Scientific Inquiry
P1.2	Scientific Reflection and Social Implications

STANDARD P2 Motion of Objects

P2.1	Position – Time
P2.2	Velocity – Time
P2.3x	Frames of Reference

STANDARD P3 Forces and Motion

P3.1	Basic Forces in Nature
P3.1x	Forces
P3.2	Net Forces
P3.3	Newton's Third Law
P3.4	Forces and Acceleration
P3.5x	Momentum
P3.6	Gravitational Interactions
P3.7	Electric Charges
P3.7x	Electric Charges – Interactions
P3.p8	Magnetic Force *(prerequisite)*
P3.8x	Electromagnetic Force

STANDARD P4 Forms of Energy and Energy Transformations

P4.1	Energy Transfer
P4.1x	Energy Transfer – Work
P4.2	Energy Transformation
P4.3	Kinetic and Potential Energy
P4.3x	Kinetic and Potential Energy – Calculations
P4.4	Wave Characteristics
P4.4x	Wave Characteristics – Calculations
P4.5	Mechanical Wave Propagation
P4.6	Electromagnetic Waves
P4.6x	Electromagnetic Propagation
P4.r7x	Quantum Theory of Waves *(recommended)*
P4.8	Wave Behavior – Reflection and Refraction
P4.8x	Wave Behavior – Diffraction, Interference, and Refraction
P4.9	Nature of Light
P4.r9x	Nature of Light – Wave-Particle Nature *(recommended)*
P4.10	Current Electricity – Circuits
P4.10x	Current Electricity – Ohm's Law, Work, and Power
P4.11x	Heat, Temperature, and Efficiency
P4.12	Nuclear Reactions
P4.12x	Mass and Energy

STANDARD P1: 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.

P1.1 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.

P1.1A Generate new questions that can be investigated in the laboratory or field.

P1.1B 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.

P1.1C 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).

P1.1D Identify patterns in data and relate them to theoretical models.

P1.1E Describe a reason for a given conclusion using evidence from an investigation.

P1.1f Predict what would happen if the variables, methods, or timing of an investigation were changed.

P1.1g Based on empirical evidence, explain and critique the reasoning used to draw a scientific conclusion or explanation.

P1.1h Design and conduct a systematic scientific investigation that tests a hypothesis. Draw conclusions from data presented in charts or tables.

P1.1i Distinguish between scientific explanations that are regarded as current scientific consensus and the emerging questions that active researchers investigate.

P1.2 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.

P1.2A Critique whether or not specific questions can be answered through scientific investigations.

P1.2B Identify and critique arguments about personal or societal issues based on scientific evidence.

P1.2C Develop an understanding of a scientific concept by accessing information from multiple sources. Evaluate the scientific accuracy and significance of the information.

P1.2D Evaluate scientific explanations in a peer review process or discussion format.

P1.2E Evaluate the future career and occupational prospects of science fields.

P1.2f Critique solutions to problems, given criteria and scientific constraints.

P1.2g Identify scientific tradeoffs in design decisions and choose among alternative solutions.

P1.2h Describe the distinctions between scientific theories, laws, hypotheses, and observations.

P1.2i Explain the progression of ideas and explanations that lead to science theories that are part of the current scientific consensus or core knowledge.

P1.2j Apply science principles or scientific data to anticipate effects of technological design decisions.

P1.2k Analyze how science and society interact from a historical, political, economic, or social perspective.

STANDARD P2: MOTION OF OBJECTS

The universe is in a state of constant change. From small particles (electrons) to the large systems (galaxies) all things are in motion. Therefore, for students to understand the universe they must describe and represent various types of motion. Kinematics, the description of motion, always involves measurements of position and time. Students must describe the relationships between these quantities using mathematical statements, graphs, and motion maps. They use these representations as powerful tools to not only describe past motions but also predict future events.

P2.1 Position — Time

An object's position can be measured and graphed as a function of time. An object's speed can be calculated and graphed as a function of time.

P2.1A Calculate the average speed of an object using the change of position and elapsed time.

P2.1B Represent the velocities for linear and circular motion using motion diagrams (arrows on strobe pictures).

P2.1C Create line graphs using measured values of position and elapsed time.

P2.1D Describe and analyze the motion that a position-time graph represents, given the graph.

P2.1E Describe and classify various motions in a plane as one dimensional, two dimensional, circular, or periodic.

P2.1F Distinguish between rotation and revolution and describe and contrast the two speeds of an object like the Earth.

P2.1g Solve problems involving average speed and constant acceleration in one dimension.

P2.1h Identify the changes in speed and direction in everyday examples of circular (rotation and revolution), periodic, and projectile motions.

P2.2 Velocity — Time

The motion of an object can be described by its position and velocity as functions of time and by its average speed and average acceleration during intervals of time.

P2.2A Distinguish between the variables of distance, displacement, speed, velocity, and acceleration.

P2.2B Use the change of speed and elapsed time to calculate the average acceleration for linear motion.

P2.2C Describe and analyze the motion that a velocity-time graph represents, given the graph.

P2.2D State that uniform circular motion involves acceleration without a change in speed.

P2.2e Use the area under a velocity-time graph to calculate the distance traveled and the slope to calculate the acceleration.

P2.2f Describe the relationship between changes in position, velocity, and acceleration during periodic motion.

P2.2g Apply the independence of the vertical and horizontal initial velocities to solve projectile motion problems.

P2.3x Frames of Reference

All motion is relative to whatever frame of reference is chosen, for there is no motionless frame from which to judge all motion.

P2.3a Describe and compare the motion of an object using different reference frames.

STANDARD P3: FORCES AND MOTION

Students identify interactions between objects either as being by direct contact (e.g., pushes or pulls, friction) or at a distance (e.g., gravity, electromagnetism), and to use forces to describe interactions between objects. They recognize that non-zero net forces always cause changes in motion (Newton's first law). These changes can be changes in speed, direction, or both. Students use Newton's second law to summarize relationships among and solve problems involving net forces, masses, and changes in motion (using standard metric units). They explain that whenever one object exerts a force on another, a force equal in magnitude and opposite in direction is exerted back on it (Newton's third law).

P3.1 Basic Forces in Nature

Objects can interact with each other by "direct contact" (e.g., pushes or pulls, friction) or at a distance (e.g., gravity, electromagnetism, nuclear).

P3.1A Identify the force(s) acting between objects in "direct contact" or at a distance.

P3.1x Forces

There are four basic forces (gravitational, electromagnetic, strong, and weak nuclear) that differ greatly in magnitude and range. Between any two charged particles, electric force is vastly greater than the gravitational force. Most observable forces (e.g., those exerted by a coiled spring or friction) may be traced to electric forces acting between atoms and molecules.

P3.1b Explain why scientists can ignore the gravitational force when measuring the net force between two electrons.

P3.1c Provide examples that illustrate the importance of the electric force in everyday life.

P3.1d Identify the basic forces in everyday interactions.

P3.2 Net Forces

Forces have magnitude and direction. The net force on an object is the sum of all the forces acting on the object. Objects change their speed and/or direction only when a net force is applied. If the net force on an object is zero, there is no change in motion (Newton's First Law).

P3.2A Identify the magnitude and direction of everyday forces (e.g., wind, tension in ropes, pushes and pulls, weight).

P3.2B Compare work done in different situations.

P3.2C Calculate the net force acting on an object.

P3.2d Calculate all the forces on an object on an inclined plane and describe the object's motion based on the forces using free-body diagrams.

P3.3 Newton's Third Law

Whenever one object exerts a force on another object, a force equal in magnitude and opposite in direction is exerted back on the first object.

P3.3A Identify the action and reaction force from examples of forces in everyday situations (e.g., book on a table, walking across the floor, pushing open a door).

P3.3b Predict how the change in velocity of a small mass compares to the change in velocity of a large mass when the objects interact (e.g., collide).

P3.3c Explain the recoil of a projectile launcher in terms of forces and masses.

P3.3d Analyze why seat belts may be more important in autos than in buses.

P3.4 Forces and Acceleration

The change of speed and/or direction (acceleration) of an object is proportional to the net force and inversely proportional to the mass of the object. The acceleration and net force are always in the same direction.

P3.4A Predict the change in motion of an object acted on by several forces.

P3.4B Identify forces acting on objects moving with constant velocity (e.g., cars on a highway).

P3.4C Solve problems involving force, mass, and acceleration in linear motion (Newton's second law).

P3.4D Identify the force(s) acting on objects moving with uniform circular motion (e.g., a car on a circular track, satellites in orbit).

P3.4e Solve problems involving force, mass, and acceleration in two-dimensional projectile motion restricted to an initial horizontal velocity with no initial vertical velocity (e.g., ball rolling off a table).

P3.4f Calculate the changes in velocity of a thrown or hit object during and after the time it is acted on by the force.

P3.4g Explain how the time of impact can affect the net force (e.g., air bags in cars, catching a ball).

P3.5x Momentum

A moving object has a quantity of motion (momentum) that depends on its velocity and mass. In interactions between objects, the total momentum of the objects does not change.

P3.5a Apply conservation of momentum to solve simple collision problems.

P3.6 Gravitational Interactions

Gravitation is a universal attractive force that a mass exerts on every other mass. The strength of the gravitational force between two masses is proportional to the masses and inversely proportional to the square of the distance between them.

P3.6A Explain earth-moon interactions (orbital motion) in terms of forces.

P3.6B Predict how the gravitational force between objects changes when the distance between them changes.

P3.6C Explain how your weight on Earth could be different from your weight on another planet.

P3.6d Calculate force, masses, or distance, given any three of these quantities, by applying the Law of Universal Gravitation, given the value of G.

P3.6e Draw arrows (vectors) to represent how the direction and magnitude of a force changes on an object in an elliptical orbit.

P3.7 Electric Charges

Electric force exists between any two charged objects. Oppositely charged objects attract, while objects with like charge repel. The strength of the electric force between two charged objects is proportional to the magnitudes of the charges and inversely proportional to the square of the distance between them (Coulomb's Law).

P3.7A Predict how the electric force between charged objects varies when the distance between them and/or the magnitude of charges change.

P3.7B Explain why acquiring a large excess static charge (e.g., pulling off a wool cap, touching a Van de Graaff generator, combing) affects your hair.

P3.7x Electric Charges — Interactions

Charged objects can attract electrically neutral objects by induction.

P3.7c Draw the redistribution of electric charges on a neutral object when a charged object is brought near.

P3.7d Identify examples of induced static charges.

P3.7e Explain why an attractive force results from bringing a charged object near a neutral object.

P3.7f Determine the new electric force on charged objects after they touch and are then separated.

P3.7g Propose a mechanism based on electric forces to explain current flow in an electric circuit.

P3.p8 Magnetic Force (prerequisite)

Magnets exert forces on all objects made of ferromagnetic materials (e.g., iron, cobalt, and nickel) as well as other magnets. This force acts at a distance. Magnetic fields accompany magnets and are related to the strength and direction of the magnetic force. *(prerequisite)*

P3.p8A Create a representation of magnetic field lines around a bar magnet and qualitatively describe how the relative strength and direction of the magnetic force changes at various places in the field. *(prerequisite)*

P3.8x Electromagnetic Force

Magnetic and electric forces are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces and moving magnets produce electric forces (e.g., electric current in a conductor).

P3.8b Explain how the interaction of electric and magnetic forces is the basis for electric motors, generators, and the production of electromagnetic waves.

STANDARD P4: FORMS OF ENERGY AND ENERGY TRANSFORMATIONS

Energy is a useful conceptual system for explaining how the universe works and accounting for changes in matter. Energy is not a "thing." Students develop several energy-related ideas: First, they keep track of energy during transfers and transformations, and account for changes using energy conservation. Second, they identify places where energy is apparently lost during a transformation process, but is actually spread around to the environment as thermal energy and therefore not easily recoverable. Third, they identify the means of energy transfers: collisions between particles, or waves.

P4.1 Energy Transfer

Moving objects and waves transfer energy from one location to another. They also transfer energy to objects during interactions (e.g., sunlight transfers energy to the ground when it warms the ground; sunlight also transfers energy from the Sun to the Earth).

P4.1A Account for and represent energy into and out of systems using energy transfer diagrams.

P4.1B Explain instances of energy transfer by waves and objects in everyday activities (e.g., why the ground gets warm during the day, how you hear a distant sound, why it hurts when you are hit by a baseball).

P4.1x Energy Transfer — Work

Work is the amount of energy transferred during an interaction. In mechanical systems, work is the amount of energy transferred as an object is moved through a distance, $W = F d$, where d is in the same direction as F. The total work done on an object depends on the net force acting on the object and the object's displacement.

P4.1c Explain why work has a more precise scientific meaning than the meaning of work in everyday language.

P4.1d Calculate the amount of work done on an object that is moved from one position to another.

P4.1e Using the formula for work, derive a formula for change in potential energy of an object lifted a distance h.

P4.2 Energy Transformation

Energy is often transformed from one form to another. The amount of energy before a transformation is equal to the amount of energy after the transformation. In most energy transformations, some energy is converted to thermal energy.

P4.2A Account for and represent energy transfer and transformation in complex processes (interactions).

P4.2B Name devices that transform specific types of energy into other types (e.g., a device that transforms electricity into motion).

P4.2C Explain how energy is conserved in common systems (e.g., light incident on a transparent material, light incident on a leaf, mechanical energy in a collision).

P4.2D Explain why all the stored energy in gasoline does not transform to mechanical energy of a vehicle.

P4.2e Explain the energy transformation as an object (e.g., skydiver) falls at a steady velocity.

P4.2f Identify and label the energy inputs, transformations, and outputs using qualitative or quantitative representations in simple technological systems (e.g., toaster, motor, hair dryer) to show energy conservation.

P4.3 Kinetic and Potential Energy

Moving objects have kinetic energy. Objects experiencing a force may have potential energy due to their relative positions (e.g., lifting an object or stretching a spring, energy stored in chemical bonds). Conversions between kinetic and gravitational potential energy are common in moving objects. In frictionless systems, the decrease in gravitational potential energy is equal to the increase in kinetic energy or vice versa.

P4.3A Identify the form of energy in given situations (e.g., moving objects, stretched springs, rocks on cliffs, energy in food).

P4.3B Describe the transformation between potential and kinetic energy in simple mechanical systems (e.g., pendulums, roller coasters, ski lifts).

P4.3C Explain why all mechanical systems require an external energy source to maintain their motion.

P4.3x Kinetic and Potential Energy — Calculations

The kinetic energy of an object is related to the mass of an object and its speed: $KE = {}^1/_2\ mv^2$.

P4.3d Rank the amount of kinetic energy from highest to lowest of everyday examples of moving objects.

P4.3e Calculate the changes in kinetic and potential energy in simple mechanical systems (e.g., pendulums, roller coasters, ski lifts) using the formulas for kinetic energy and potential energy.

P4.3f Calculate the impact speed (ignoring air resistance) of an object dropped from a specific height or the maximum height reached by an object (ignoring air resistance), given the initial vertical velocity.

P4.4 Wave Characteristics

Waves (mechanical and electromagnetic) are described by their wavelength, amplitude, frequency, and speed.

P4.4A Describe specific mechanical waves (e.g., on a demonstration spring, on the ocean) in terms of wavelength, amplitude, frequency, and speed.

P4.4B Identify everyday examples of transverse and compression (longitudinal) waves.

P4.4C Compare and contrast transverse and compression (longitudinal) waves in terms of wavelength, amplitude, and frequency.

P4.4x Wave Characteristics — Calculations

Wave velocity, wavelength, and frequency are related by $v = \lambda f$. The energy transferred by a wave is proportional to the square of the amplitude of vibration and its frequency.

P4.4d Demonstrate that frequency and wavelength of a wave are inversely proportional in a given medium.

P4.4e Calculate the amount of energy transferred by transverse or compression waves of different amplitudes and frequencies (e.g., seismic waves).

P4.5 Mechanical Wave Propagation

Vibrations in matter initiate mechanical waves (e.g., water waves, sound waves, seismic waves), which may propagate in all directions and decrease in intensity in proportion to the distance squared for a point source. Waves transfer energy from one place to another without transferring mass.

P4.5A Identify everyday examples of energy transfer by waves and their sources.

P4.5B Explain why an object (e.g., fishing bobber) does not move forward as a wave passes under it.

P4.5C Provide evidence to support the claim that sound is energy transferred by a wave, not energy transferred by particles.

P4.5D Explain how waves propagate from vibrating sources and why the intensity decreases with the square of the distance from a point source.

P4.5E Explain why everyone in a classroom can hear one person speaking, but why an amplification system is often used in the rear of a large concert auditorium.

P4.6 Electromagnetic Waves

Electromagnetic waves (e.g., radio, microwave, infrared, visible light, ultraviolet, x-ray) are produced by changing the motion (acceleration) of charges or by changing magnetic fields. Electromagnetic waves can travel through matter, but they do not require a material medium. (That is, they also travel through empty space.) All electromagnetic waves move in a vacuum at the speed of light. Types of electromagnetic radiation are distinguished from each other by their wavelength and energy.

P4.6A Identify the different regions on the electromagnetic spectrum and compare them in terms of wavelength, frequency, and energy.

P4.6B Explain why radio waves can travel through space, but sound waves cannot.

P4.6C Explain why there is a delay between the time we send a radio message to astronauts on the moon and when they receive it.

P4.6D Explain why we see a distant event before we hear it (e.g., lightning before thunder, exploding fireworks before the boom).

P4.6x Electromagnetic Propagation

Modulated electromagnetic waves can transfer information from one place to another (e.g., televisions, radios, telephones, computers and other information technology devices). Digital communication makes more efficient use of the limited electromagnetic spectrum, is more accurate than analog transmission, and can be encrypted to provide privacy and security.

P4.6e Explain why antennas are needed for radio, television, and cell phone transmission and reception.

P4.6f Explain how radio waves are modified to send information in radio and television programs, radio-control cars, cell phone conversations, and GPS systems.

P4.6g Explain how different electromagnetic signals (e.g., radio station broadcasts or cell phone conversations) can take place without interfering with each other.

P4.6h Explain the relationship between the frequency of an electromagnetic wave and its technological uses.

P4.r7x Quantum Theory of Waves *(recommended)*

Electromagnetic energy is transferred on the atomic scale in discrete amounts called quanta. The equation $E = hf$ quantifies the relationship between the energy transferred and the frequency, where h is Planck's constant. *(recommended)*

P4.r7a Calculate and compare the energy in various electromagnetic quanta (e.g., visible light, x-rays). *(recommended)*

P4.8 Wave Behavior — Reflection and Refraction

The laws of reflection and refraction describe the relationships between incident and reflected/refracted waves.

P4.8A Draw ray diagrams to indicate how light reflects off objects or refracts into transparent media.

P4.8B Predict the path of reflected light from flat, curved, or rough surfaces (e.g., flat and curved mirrors, painted walls, paper).

P4.8x Wave Behavior — Diffraction, Interference, and Refraction

Waves can bend around objects (diffraction). They also superimpose on each other and continue their propagation without a change in their original properties (interference). When refracted, light follows a defined path.

P4.8c Describe how two wave pulses propagated from opposite ends of a demonstration spring interact as they meet.

P4.8d List and analyze everyday examples that demonstrate the interference characteristics of waves (e.g., dead spots in an auditorium, whispering galleries, colors in a CD, beetle wings).

P4.8e Given an angle of incidence and indices of refraction of two materials, calculate the path of a light ray incident on the boundary (Snell's Law).

P4.8f Explain how Snell's Law is used to design lenses (e.g., eye glasses, microscopes, telescopes, binoculars).

P4.9 Nature of Light

Light interacts with matter by reflection, absorption, or transmission.

P4.9A Identify the principle involved when you see a transparent object (e.g., straw, piece of glass) in a clear liquid.

P4.9B Explain how various materials reflect, absorb, or transmit light in different ways.

P4.9C Explain why the image of the Sun appears reddish at sunrise and sunset.

P4.r9x Nature of Light — Wave-Particle Nature *(recommended)*

The dual wave-particle nature of matter and light is the foundation for modern physics. *(recommended)*

P4.r9d Describe evidence that supports the dual wave - particle nature of light. *(recommended)*

P4.10 Current Electricity — Circuits

Current electricity is described as movement of charges. It is a particularly useful form of energy because it can be easily transferred from place to place and readily transformed by various devices into other forms of energy (e.g., light, heat, sound, and motion). Electrical current (amperage) in a circuit is determined by the potential difference (voltage) of the power source and the resistance of the loads in the circuit.

P4.10A Describe the energy transformations when electrical energy is produced and transferred to homes and businesses.

P4.10B Identify common household devices that transform electrical energy to other forms of energy, and describe the type of energy transformation.

P4.10C Given diagrams of many different possible connections of electric circuit elements, identify complete circuits, open circuits, and short circuits and explain the reasons for the classification.

P4.10D Discriminate between voltage, resistance, and current as they apply to an electric circuit.

P4.10x Current Electricity — Ohm's Law, Work, and Power

In circuits, the relationship between electric current, I, electric potential difference, V, and resistance, R, is quantified by $V = I R$ (Ohm's Law). Work is the amount of energy transferred during an interaction. In electrical systems, work is done when charges are moved through the circuit. Electric power is the amount of work done by an electric current in a unit of time, which can be calculated using $P = I V$.

P4.10e Explain energy transfer in a circuit, using an electrical charge model.

P4.10f Calculate the amount of work done when a charge moves through a potential difference, V.

P4.10g Compare the currents, voltages, and power in parallel and series circuits.

P4.10h Explain how circuit breakers and fuses protect household appliances.

P4.10i Compare the energy used in one day by common household appliances (e.g., refrigerator, lamps, hair dryer, toaster, televisions, music players).

P4.10j Explain the difference between electric power and electric energy as used in bills from an electric company.

P4.11x Heat, Temperature, and Efficiency

Heat is often produced as a by-product during energy transformations. This energy is transferred into the surroundings and is not usually recoverable as a useful form of energy. The efficiency of systems is defined as the ratio of the useful energy output to the total energy input. The efficiency of natural and human-made systems varies due to the amount of heat that is not recovered as useful work.

P4.11a Calculate the energy lost to surroundings when water in a home water heater is heated from room temperature to the temperature necessary to use in a dishwasher, given the efficiency of the home hot water heater.

P4.11b Calculate the final temperature of two liquids (same or different materials) at the same or different temperatures and masses that are combined.

P4.12 Nuclear Reactions

Changes in atomic nuclei can occur through three processes: fission, fusion, and radioactive decay. Fission and fusion can convert small amounts of matter into large amounts of energy. Fission is the splitting of a large nucleus into smaller nuclei at extremely high temperature and pressure. Fusion is the combination of smaller nuclei into a large nucleus and is responsible for the energy of the Sun and other stars. Radioactive decay occurs naturally in the Earth's crust (rocks, minerals) and can be used in technological applications (e.g., medical diagnosis and treatment).

P4.12A Describe peaceful technological applications of nuclear fission and radioactive decay.

P4.12B Describe possible problems caused by exposure to prolonged radioactive decay.

P4.12C Explain how stars, including our Sun, produce huge amounts of energy (e.g., visible, infrared, ultraviolet light).

P4.12x Mass and Energy

In nuclear reactions, a small amount of mass is converted to a large amount of energy, $E = mc^2$, where c is the speed of light in a vacuum. The amount of energy before and after nuclear reactions must consider mass changes as part of the energy transformation.

P4.12d Identify the source of energy in fission and fusion nuclear reactions.