



Diocese of Alexandria ~ Catholic Schools

Where faith and knowledge grow



DIOCESE OF ALEXANDRIA

As the Diocese of Alexandria seeks to provide a comprehensive learning environment, we are charged to “Teach More” by showing how all learning flows from and relates to our Creator. In this way, we will give our teaching a deeper meaning and purpose than simply the content itself. With this as our goal, the Catholic Schools Office has intertwined our selected curricular standards with the Catholic Standards developed by the Cardinal Newman Society. Through the merging of these two curricula, English Language Arts, Mathematics, Science, and Social Studies, teachers will be provided a roadmap to guide student’s understanding and recognition of the relationship between learning and the connection to our God.

Thomas E. Roque, Sr.
Superintendent of Catholic Schools



DIOCESE OF ALEXANDRIA

Through comprehensive review of curricula from high performing districts throughout the United States in combination with parochial schools and Newman Cardinal Standards, the Curriculum Team for the Diocese of Alexandria has generated curricula for English Language Arts, Mathematics, Science, and Social Studies. The development of this framework is designed to guide the instructional path of teachers as they focus on the formation of their students in the areas of faith, academic excellence, responsible citizenry, and effective communication and collaboration. This process is a continuous improvement process with no defined beginning or end.

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Frameworks



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HOW TO USE

The frameworks are guides to instruction. The frameworks assist teachers in planning and pacing instruction. Specific dates or weeks that may be included in this document are for reference. Each school and teacher must consider the make-up of their students, focusing on the needs and strengths of each child when pacing and planning instruction.

The cycles for the year help pace instruction and ensure students have consistent coverage of the content. The duration (the suggested amount of time to spend on each cycle) does not accommodate for the scheduling of special events, inclement weather or school events. Teachers, with principal guidance, should adjust pacing as needed to accommodate for these events.

RESEARCH-BASED HIGH-YIELD PRACTICES FOR INSTRUCTION

These strategies have proven effective in affecting student learning and achievement gains. As you plan daily instruction, consider how and where to integrate these strategies into the instructional sequence. Effect size is in parentheses. Please refer to the works of John Hattie for a complete description of instructional effect size.

- Classroom Discussion/Discourse (.82)
- Teacher Clarity/making the learning visible with expectations for learning (.75)
- Reciprocal Teaching (.74)
- Feedback (.73)
- Metacognitive Strategies (.69)

Chemistry



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Unit 1: STRUCTURE AND PROPERTIES OF MATTER

Summary

Instructional Days: 30

How can the substructures of atoms explain the observable properties of substances?

In this unit of study, students use investigations, simulations, and models to make sense of the substructure of atoms and to provide more mechanistic explanations of the properties of substances. Chemical reactions, including rates of reactions and energy changes, can be understood by students at this level in terms of the collisions of molecules and the rearrangements of atoms. Students are able to use the periodic table as a tool to explain and predict the properties of elements. Students are expected to communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. The crosscutting concepts of *structure and function*, *patterns*, *energy and matter*, and *stability and change* are called out as the framework for understanding the disciplinary core ideas. Students use *developing and using models*, *planning and conducting investigations*, *using mathematical thinking*, and *constructing explanations and designing solutions*. Students are also expected to use the science and engineering practices to demonstrate proficiency with the core ideas.

Student Learning Objectives

Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. *[Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] [Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.]* (HS-PS1-1)

Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. *[Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] [Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.]* (HS-PS1-2)

Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. *[Clarification Statement: Emphasis is on understanding the strengths of forces between particles, not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension.] [Assessment Boundary: Assessment does not include Raoult's law calculations of vapor pressure.]* (HS-PS1-3)

Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.* *[Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.]* *[Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.]*
(HS-PS2-6)

Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.**(HS-ETS1-3)**

Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem. (HS-ETS1-4)

Unit Sequence

Part A: How can a periodic table tell me about the subatomic structure of a substance?

Concepts	Concepts
• Different patterns may be observed at each of the scales at which a system is studied, and these patterns can provide evidence for causality in explanations of phenomena. • Each atom has a charged substructure. • An atom's nucleus is made of protons and neutrons and is surrounded by electrons. • The periodic table orders elements horizontally by number of protons in the nucleus of each element's atoms and places elements with similar chemical properties in columns. • The repeating patterns of this table reflect patterns of outer electron states. • Patterns of electrons in the outermost energy level of atoms can provide evidence for the relative properties of elements at different scales. • Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.	<i>Students who understand the concepts are able to:</i> • Use the periodic table as a model to provide evidence for relative properties of elements at different scales based on the patterns of electrons in the outermost energy level of atoms in main group elements. • Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms in main group elements.

Unit Sequence	
Part B: <i>How can I use the periodic table to predict if I need to duck before mixing two elements?</i>	
Concepts	Concepts
- The periodic table orders elements horizontally by number of protons in the nucleus of each element's atoms and places elements with similar chemical properties in columns. - The repeating patterns of the periodic table reflect patterns of outer electron states. - The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. - Different patterns may be observed at each of the scales at which a system is studied, and these patterns can provide evidence for causality in explanations of phenomena.	<i>Students who understand the concepts are able to:</i> - Use valid and reliable evidence (obtained from students' own investigations, models, theories, simulations, and peer review) showing the outermost electron states of atoms, trends in the periodic table, and patterns of chemical properties to construct and revise an explanation for the outcome of a simple chemical reaction. - Use the assumption that theories and laws that describe the outcome of simple chemical reactions operate today as they did in the past and will continue to do so in the future. - Observe patterns in the outermost electron states of atoms, trends in the periodic table, and chemical properties. - Use the conservation of atoms and the chemical properties of the elements involved to describe and predict the outcome of a chemical reaction.

Unit Sequence	
Part C: <i>How can I use the properties of something (in bulk quantities) to predict what is happening with the subatomic particles?</i>	
Concepts	Formative Assessment
- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. - Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. - Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.	<i>Students who understand the concepts are able to:</i> - Plan and conduct an investigation individually and collaboratively to produce data that can serve as the basis for evidence for comparing the structure of substances at the bulk scale to infer the strength of electrical forces between particles. In the investigation design, decide on types, how much, and accuracy of data needed to produce reliable measurements; consider limitations on the precision of the data (e.g., number of trials, cost, risk, time); and refine the design accordingly. - Use patterns in the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

Unit Sequence

Part D: I want to do the right thing, what is the greener choice for *grocery bags (paper or plastic/reusable vs. disposable)*; *cold drink containers (plastic, glass, or aluminum)*; or *hot drink containers (paper, Styrofoam, or ceramic)*? *[Clarification: Students should have the opportunity to select the product and use the Life Cycle Analysis (LCA) to make an evidence-based claim.]*

Concepts	Formative Assessment
- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. - Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. - When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, aesthetics, and to consider social, cultural, and environmental impacts. - Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. - Models (e.g., physical, mathematical, computer models) can be used to simulate why the molecular-level structure is important in the functioning of designed materials.	<i>Students who understand the concepts are able to:</i> - Communicate scientific and technical information about why the molecular - level structure is important in the functioning of designed materials. - Evaluate a solution to a complex real-world problem based on scientific knowledge, student generated sources of evidence, prioritized criteria, and tradeoffs considerations to determine why the molecular level structure is important in the functioning of designed materials. - Use mathematical models and/or computer simulations to show why the molecular level structure is important in the functioning of designed materials. - Communicate scientific and technical information about the attractive and repulsive forces that determine the functioning of the material. - Use mathematical models and/or computer simulations to show the attractive and repulsive forces that determine the functioning of the material. - Examine in detail the properties of designed materials, the structure of the components of designed materials, and the connections of the components to reveal the function. - Use models (e.g., physical, mathematical, computer models) to simulate systems of designed materials and interactions--including energy, matter, and information flows--within and between designed materials at different scales.

Sample of Open Education Resources
<u>Build an Atom</u>: This simulation allows students to create different illustrations of atoms and provides evidence that protons determine the identity of the element. <u>Periodic Table Trends</u>: This is a virtual investigation of the periodic trends. <u>Path to Periodic Table</u>: This investigation provides students with the opportunity to make sense of how and why the periodic table is organized the way that it is. Students will re-create the thought process that Dmitri Mendeleev and Julius Lothar Meyer went through to devise their early periodic tables. <u>Castle of Mendeleev</u>: Students engage in a fantasy world that requires them to make claims, based on evidence, regarding the identity of unknown materials. <u>Shall We Dance? - Classifying Types of Chemical Reactions</u>: Students identify and differentiate between four types of chemical reactions: synthesis, decomposition, single replacement and double replacement. Students also develop models for chemical reactions and identify the limitations of the models using evidence.

Teacher Professional Learning Resources

Appendix A: NGSS and Foundations for the Unit

Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. *[Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] [Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.]* (HS-PS1-1)

Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. *[Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] [Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.]* (HS-PS1-2)

Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. *[Clarification Statement: Emphasis is on understanding the strengths of forces between particles, not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension.] [Assessment Boundary: Assessment does not include Raoult's law calculations of vapor pressure.]* (HS-PS1-3)

Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. *[Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.]* (HS-PS2-6)

Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. (HS-ETS1-3)

Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem. (HS-ETS1-4)

The Student Learning Objectives above were developed using the following elements from the NRC document
A Framework for K-12 Science Education:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models - Use a model to predict the relationships between systems or between components of a system. (HS-PS1-1) Planning and Carrying Out Investigations - Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS1-3) Constructing Explanations and Designing Solutions - Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-PS1-2) - Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-	PS1.A: Structure and Properties of Matter - Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (HS-PS1-1) - The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (HS-PS1-1),(HS-PS1-2) - The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (<i>secondary to HS-PS2-6</i>) PS1.B: Chemical Reactions - The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-2) PS2.B: Types of Interactions - Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. (<i>secondary to HS-</i>	Patterns - Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS1-1),(HS-PS1-2),(HS-PS1-3) Structure and Function - Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. (HS-PS2-6) Systems and System Models - Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows— within and between systems at different scales. (HS-ETS1-4) Connections to Engineering, Technology, and Applications of Science Influence of Science, Engineering, and Technology on Society and the Natural World New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions

generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3) Obtaining, Evaluating, and Communicating Information - Communicate scientific and technical information (e.g. about the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (HS-PS2-6) Using Mathematics and Computational Thinking - Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. (HS-ETS1-4)	<i>PS1-1),(secondary to HS-PS1-3)</i> ESS2.D: Weather and Climate - Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. (HS-ESS2-6) ETS1.B: Developing Possible Solutions - When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3) - Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4)	about technology. (HS-ETS1-1) (HS-ETS1-3)
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Chemistry



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Unit 2: THE CHEMISTRY OF ABIOTIC SYSTEMS

Summary

Instructional Days: 30

Why are we so lucky that water has the physical properties that it does?

How do ancient carbon atoms drive economic decisions in the modern world?

In this unit of study, students *develop and use models, plan and carry out investigations, analyze and interpret data, and engage in argument from evidence* to make sense of energy as a quantitative property of a system—a property that depends on the motion and interactions of matter and radiation within that system. They will also use the findings of investigations to provide a mechanistic explanation for the core idea that total change of energy in any system is always equal to the total energy transferred into or out of the system. Additionally, students develop an understanding that energy, at both the macroscopic and the atomic scales, can be accounted for as motions of particles or as energy associated with the configurations (relative positions) of particles.

Students apply their understanding of energy to explain the role that water plays in affecting weather. Students examine the ways that human activities cause feedback that create changes to other systems. Students are expected to demonstrate proficiency in *developing and using models, planning and carrying out investigations, analyzing and interpreting data, engaging in argument from evidence*, and using these practices to demonstrate understanding of core ideas.

Students also develop possible solutions for major global problems. They begin by breaking these problems into smaller problems that can be tackled with engineering methods. To evaluate potential solutions, students are expected not only to consider a wide range of criteria, but also to recognize that criteria need to be prioritized.

This unit is based on HS-PS3-4, HS-ESS2-5, HS-ESS3-2, and HS-ETS1-3.

Student Learning Objectives

Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). *[Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.] (HS-PS3-4)*

Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes. *[Clarification Statement: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations include stream transportation and deposition using a stream table, erosion using variations in soil moisture content, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).] (HS-ESS2-5)*

Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.* *[Clarification Statement: Emphasis is on the conservation, recycling, and reuse of resources (such as minerals and metals) where possible, and on minimizing impacts where it is not. Examples include developing best practices for agricultural soil use, mining (for coal, tar sands, and oil shales), and pumping (for petroleum and natural gas). Science knowledge indicates what can happen in natural systems—not what should happen.]* (HS-ESS3-2)

Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts. *[Clarification Statement: See Three-Dimensional Teaching and Learning Section for examples].* (HS-ETS1-3)

Unit Sequence	
Part A: Does thermal energy always transfer or transform in predictable ways?	
Concepts	Concepts
- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. - Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. - Uncontrolled systems always move toward more stable states—that is, toward a more uniform energy distribution. - Although energy cannot be destroyed, it can be converted into less useful forms—for example, to thermal energy in the surrounding environment.	<i>Students who understand the concepts are able to:</i> - Plan and conduct an investigation individually or collaboratively to produce data on transfer of thermal energy in a closed system that can serve as a basis for evidence of uniform energy distribution among components of a system when two components of different temperatures are combined. - Use models to describe a system and define its boundaries, initial conditions, inputs, and outputs. - Design an investigation to produce data on transfer of thermal energy in a closed system that can serve as a basis for evidence of uniform energy distribution among components of a system when two components of different temperatures are combined, considering types, how much, and the accuracy of data needed to produce reliable measurements. - Consider the limitations of the precision of the data collected and refine the design accordingly.

Unit Sequence

Part B: *What makes water's properties essential to life on our planet? or Why do we look for water on other planets? or What makes water so special?*

Concepts

- The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics.
- The functions and properties of water and water systems can be inferred from the overall structure, the way the components are shaped and used, and the molecular substructure.
 - These properties include water's exceptional capacity to absorb, store, and release large amounts of energy; transmit sunlight; expand upon freezing; dissolve and transport materials; and lower the viscosities and melting points of rocks.

Concepts

Students who understand the concepts are able to:

- Plan and conduct an investigation individually and collaboratively of the properties of water and its effects on Earth materials and surface processes.
- Use models to describe a hydrological system and define its boundaries, initial conditions, inputs, and outputs.
- Design an investigation considering the types, how much, and accuracy of data needed to produce reliable measurements.
- Consider the limitations on the precision of the data collected and refine the design accordingly.

Unit Sequence	
Part C: <i>What is the best energy source for a home? How would I meet the energy needs of the house of the future?</i>	
Concepts	Formative Assessment
• All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors. • Models can be used to simulate systems and interactions, including energy, matter, and information flows, within and between systems at different scales. • Engineers continuously modify design solutions to increase benefits while decreasing costs and risks. • Analysis of costs and benefits is a critical aspect of decisions about technology. • Scientific knowledge indicates what can happen in natural systems, not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge. • New technologies can have deep impacts on society and the environment, including some that were not anticipated. • Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. • Many decisions are made not using science alone, but instead relying on social and cultural contexts to resolve issues.	<i>Students who understand the concepts are able to:</i> • Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost benefit ratios, scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g., economic, societal, environmental, and ethical considerations). • Use models to evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios, scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g., economic, societal, environmental, and ethical considerations).
Teacher Professional Learning Resources	

Instructional Resources

Note- The majority of the student sense-making experiences found at these links predate the NGSS. Most will need to be modified to include science and engineering practices, disciplinary core ideas, and cross cutting concepts. [The EQuIP Rubrics for Science](#) can be used as a blueprint for evaluating and modifying instructional materials.

- American Association for the Advancement of Science: <http://www.aaas.org/programs>
- American Association of Physics Teachers: <http://www.aapt.org/resources/>
- American Chemical Society: <http://www.acs.org/content/acs/en/education.html>
- Concord Consortium: Virtual Simulations: <http://concord.org/>
- International Technology and Engineering Educators Association: <http://www.iteaconnect.org/>
- National Earth Science Teachers Association: <http://www.nestanet.org/php/index.php>
- National Science Digital Library: <https://nsdl.oercommons.org/>
- National Science Teachers Association: <http://ngss.nsta.org/Classroom-Resources.aspx>
- North American Association for Environmental Education: <http://www.naaee.net/>
- Phet: Interactive Simulations <https://phet.colorado.edu/>
- Physics Union Mathematics (PUM): <http://pum.rutgers.edu/>
- Science NetLinks: <http://www.aaas.org/program/science-netlinks>

Appendix A: NGSS and Foundations for the Unit

Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). *[Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.]* **(HS-PS3-4)**

Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes. *[Clarification Statement: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations include stream transportation and deposition using a stream table, erosion using variations in soil moisture content, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).]* **(HS-ESS2-5)**

Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.* *[Clarification Statement: Emphasis is on the conservation, recycling, and reuse of resources (such as minerals and metals) where possible, and on minimizing impacts where it is not. Examples include developing best practices for agricultural soil use, mining (for coal, tar sands, and oil shales), and pumping (for petroleum and natural gas). Science knowledge indicates what can happen in natural systems—not what should happen.]* **(HS-ESS3-2)**

Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts. *[Clarification Statement: See Three-Dimensional Teaching and Learning Section for examples].* **(HS-ETS1-3)**

The performance expectations above were developed using the following elements from the NRC document
A Framework for K-12 Science Education:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Planning and Carrying Out Investigations Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the	PS3.B: Conservation of Energy and Energy Transfer - Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-4) - Uncontrolled systems always evolve toward more stable states—that is,	Systems and System Models - When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. (HS-PS3-4) Structure and Function - The functions and properties of

data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS3-4) Engaging in Argument from Evidence - Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations). (HS-ESS3-2) Planning and Carrying Out Investigations - Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-ESS2-5) Constructing Explanations and Designing Solutions - Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)	toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). (HS-PS3-4) PS3.D: Energy in Chemical Processes - Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-4) ESS3.A: Natural Resources - All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors. (HS-ESS3-2) ETS1.B: Developing Possible Solutions - When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (<i>secondary to HS-ESS3-2</i>),(<i>secondary HS-ESS3-4</i>) ESS2.C: The Roles of Water in Earth's Surface Processes - The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store,	natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials. (HS-ESS2-5) <i>Connections to Engineering, Technology, and Applications of Science</i> Influence of Science, Engineering, and Technology on Society and the Natural World - Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ESS3-2) Influence of Science, Engineering, and Technology on Society and the Natural World - New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-1) (HS-ETS1-3) <i>Connections to Nature of Science</i> Science Addresses Questions About the Natural and Material World - Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. (HS-ESS3-2) - Science knowledge indicates what can happen in natural systems—not what should happen. The latter involves ethics, values, and human
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	and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks. (HS-ESS2-5) ETS1.A: Defining and Delimiting Engineering Problems - Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1) - Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1) ETS1.B: Developing Possible Solutions - When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3) - Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of	decisions about the use of knowledge. (HS-ESS3-2) Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues. (HS-ESS3-2)
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	solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4) ETS1.C: Optimizing the Design Solution • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)	
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Chemistry



THE DIOCESE
of ALEXANDRIA

Unit 2b: ENERGY IN CHEMICAL SYSTEMS

Summary

Instructional Days: 20

How is energy transferred within a system?

Unit 2B is used in a chemistry course when **Unit 2: The Chemistry of Abiotic Systems** is taught in the **Capstone Science Course**. In Energy of Chemical Systems, students will understand energy as a quantitative property of a system—a property that depends on the motion and interactions of matter and radiation within that system. They will also understand that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Students develop an understanding that energy, at both the macroscopic and the atomic scales, can be accounted for as motions of particles or as energy associated with the configurations (relative positions) of particles.

Students understand the role that water plays in affecting weather. Students can examine the ways that human activities cause feedback that create changes to other systems. Students are expected to demonstrate proficiency in *developing and using models, planning and carrying out investigations, analyzing and interpreting data, engaging in argument from evidence*, and using these practices to demonstrate understanding of core ideas.

Student Learning Objectives

Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). *[Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.]* **(HS-PS3-4)**

Unit Sequence	
Part A: Does thermal energy always transfer or transform in predictable ways?	
Concepts	Formative Assessment
- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. - Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. - Uncontrolled systems always move toward more stable states—that is, toward a more uniform energy distribution. - Although energy cannot be destroyed, it can be converted into less useful forms—for example, to thermal energy in the surrounding environment.	<i>Students who understand the concepts are able to:</i> - Plan and conduct an investigation individually or collaboratively to produce data on transfer of thermal energy in a closed system that can serve as a basis for evidence of uniform energy distribution among components of a system when two components of different temperatures are combined. - Use models to describe a system and define its boundaries, initial conditions, inputs, and outputs. - Design an investigation to produce data on transfer of thermal energy in a closed system that can serve as a basis for evidence of uniform energy distribution among components of a system when two components of different temperatures are combined, considering types, how much, and the accuracy of data needed to produce reliable measurements. - Consider the limitations of the precision of the data collected and refine the design accordingly
Teacher Professional Learning Resources	

Instructional Resources

***Note-** The majority of the student sense-making experiences found at these links predate the NGSS. Most will need to be modified to include science and engineering practices, disciplinary core ideas, and cross cutting concepts. [The EQuIP Rubrics for Science](#) can be used as a blueprint for evaluating and modifying instructional materials.*

- American Association for the Advancement of Science: <http://www.aaas.org/programs>
- American Association of Physics Teachers: <http://www.aapt.org/resources/>
- American Chemical Society: <http://www.acs.org/content/acs/en/education.html>
- Concord Consortium: Virtual Simulations: <http://concord.org/>
- International Technology and Engineering Educators Association: <http://www.iteaconnect.org/>
- National Earth Science Teachers Association: <http://www.nestanet.org/php/index.php>
- National Science Digital Library: <https://nsdl.oercommons.org/>
- National Science Teachers Association: <http://ngss.nsta.org/Classroom-Resources.aspx>
- North American Association for Environmental Education: <http://www.naaee.net/>
- Phet: Interactive Simulations <https://phet.colorado.edu/>
- Physics Union Mathematics (PUM): <http://pum.rutgers.edu/>
- Science NetLinks: <http://www.aaas.org/program/science-netlinks>

Appendix A: NGSS and Foundations for the Unit

Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). *[Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.] (HS-PS3-4)*

The performance expectations above were developed using the following elements from the NRC document
A Framework for K-12 Science Education:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Planning and Carrying Out Investigations Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS3-4)	PS3.B: Conservation of Energy and Energy Transfer - Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-4) - Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). (HS-PS3-4) PS3.D: Energy in Chemical Processes - Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-4)	Systems and System Models When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. (HS-PS3-4)

Chemistry



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Unit 3: BONDING AND CHEMICAL REACTIONS

Summary

Instructional Days: 30

How can one explain the structure, properties, and interactions of matter?

In this unit of study, students *develop and using models, plan and conduct investigations, use mathematical thinking, and construct explanations and design solutions* as they develop an understanding of the substructure of atoms and to provide more mechanistic explanations of the properties of substances. Chemical reactions, including rates of reactions and energy changes, can be understood by students at this level in terms of the collisions of molecules and the rearrangements of atoms. Students also apply an understanding of the process of *optimization and engineering design* to chemical reaction systems. The crosscutting concepts of *patterns, energy and matter, and stability and change* are the organizing concepts for these disciplinary core ideas. Students are expected to demonstrate proficiency in *developing and using models, planning and conducting investigations, using mathematical thinking, and constructing explanations and designing solutions*.

Student Learning Objectives

Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. *[Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem-solving techniques.] [Assessment Boundary: Assessment does not include complex chemical reactions.] (HS-PS1-7)*

Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. *[Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.] [Assessment Boundary: Assessment does not include calculating the total bond energy changes during a chemical reaction from the bond energies of reactants and products.] (HS-PS1-4)*

Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. *[Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.] (HS-PS1-5)*

Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium. *[Clarification Statement: Emphasis is on the application of Le Chatlier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.]* **(HS-PS1-6)**

Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. **(HS-ETS1-2)**

Unit Sequence

Part A: *Where do the atoms go during a chemical reaction?*

Concepts	Formative Assessment
- The fact that atoms are conserved, together with the knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. - The total amount of energy and matter in closed systems is conserved. - The total amount of energy and matter in a chemical reaction system is conserved. - Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. - Changes of energy and matter in a chemical reaction system can be described in terms of energy and matter flows into, out of, and within that system.	<i>Students who understand the concepts are able to:</i> - Use mathematical representations of chemical reaction systems to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. - Use mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale, using the mole as the conversion from the atomic to the macroscopic scale. - Use the fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, to describe and predict chemical reactions. - Describe changes of energy and matter in a chemical reaction system in terms of energy and matter flows into, out of, and within that system.

Unit Sequence

Part B: What is different inside a heat pack and a cold pack?

Concepts	Formative Assessment
• A stable molecule has less energy than the same set of atoms separated; at least this much energy must be provided in order to take the molecule apart. • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. • Changes of energy and matter in a chemical reaction system can be described in terms of collisions of molecules and the rearrangements of atoms into new molecules, with subsequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. • Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.	<i>Students who understand the concepts are able to:</i> • Explain the idea that a stable molecule has less energy than the same set of atoms separated. • Describe changes of energy and matter in a chemical reaction system in terms of energy and matter flows into, out of, and within that system. • Describe chemical processes, their rates, and whether or not they store or release energy in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. • Develop a model based on evidence to illustrate the relationship between the release or absorption of energy from a chemical reaction system and the changes in total bond energy.

Unit Sequence

Part C: *Is it possible to change the rate of a reaction or cause two elements to react that do not normally want to?*

Concepts	Formative Assessment
• Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. • Patterns in the effects of changing the temperature or concentration of the reacting particles can be used to provide evidence for causality in the rate at which a reaction occurs.	<i>Students who understand the concepts are able to:</i> • Use the number and energy of collisions between molecules (particles) to explain the effects of changing the temperature or concentration of the reacting articles on the rate at which a reaction occurs. • Use patterns in the effects of changing the temperature or concentration of the reactant particles to provide evidence for causality in the rate at which a reaction occurs. • Apply scientific principles and multiple and independent student-generated sources of evidence to provide an explanation of the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

Unit Sequence	
Part D: <i>What can we do to make the products of a reaction stable?</i>	
Concepts	Formative Assessment
• Much of science deals with constructing explanations of how things change and how they remain stable. • In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others may be needed. • Explanations can be constructed explaining how chemical reaction systems can change and remain stable.	<i>Students who understand the concepts are able to:</i> • Construct explanations for how chemical reaction systems change and how they remain stable. • Design a solution to specify a change in conditions that would produce increased amounts of products at equilibrium in a chemical system based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. • Break down and prioritize criteria for increasing amounts of products in a chemical system at equilibrium. • Refine the design of a solution to specify a change in conditions that would produce increased amounts of products at equilibrium in a chemical system based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Teacher Professional Learning Resources

Instructional Resources

Note- The majority of the student sense-making experiences found at these links predate the NGSS. Most will need to be modified to include science and engineering practices, disciplinary core ideas, and cross cutting concepts. [The EQuIP Rubrics for Science](#) can be used as a blueprint for evaluating and modifying instructional materials.

- American Association for the Advancement of Science: <http://www.aaas.org/programs>
- American Chemical Society: <http://www.acs.org/content/acs/en/education.html>
- Concord Consortium: Virtual Simulations: <http://concord.org/>
- International Technology and Engineering Educators Association: <http://www.iteaconnect.org/>
- National Earth Science Teachers Association: <http://www.nestanet.org/php/index.php>
- National Science Digital Library: <https://nsdl.oercommons.org/>
- National Science Teachers Association: <http://ngss.nsta.org/Classroom-Resources.aspx>
- North American Association for Environmental Education: <http://www.naaee.net/>
- Phet: Interactive Simulations <https://phet.colorado.edu/>
- Science NetLinks: <http://www.aaas.org/program/science-netlinks>

Appendix A: NGSS and Foundations for the Unit

Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. *[Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem-solving techniques.] [Assessment Boundary: Assessment does not include complex chemical reactions.] (HS-PS1-7)*

Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. *[Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.] [Assessment Boundary: Assessment does not include calculating the total bond energy changes during a chemical reaction from the bond energies of reactants and products.] (HS-PS1-4)*

Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. *[Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.] (HS-PS1-5)*

Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.* *[Clarification Statement: Emphasis is on the application of Le Chatelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.] (HS-PS1-6)*

Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. (HS-ETS1-2)

The Student Learning Objectives above were developed using the following elements from the NRC document
A Framework for K-12 Science Education:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Develop a model based on evidence to illustrate the relationships between systems or between components of a	PS1.A: Structure and Properties of Matter Each atom has a charged substructure consisting of a nucleus, which is made of protons	Patterns Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in

system. (HS-PS1-4),(HS-PS1-8) • Use a model to predict the relationships between systems or between components of a system. (HS-PS1-1) Planning and Carrying Out Investigations • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS1-3) Using Mathematics and Computational Thinking • Use mathematical representations of phenomena to support claims. (HS-PS1-7) Constructing Explanations and Designing Solutions • Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. (HS-PS1-5) • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in	and neutrons, surrounded by electrons. (HS-PS1-1) • The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (HS-PS1-1),(HS-PS1-2) • The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (HS-PS1-3),(secondary to HS-PS2-6) • A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. (HS-PS1-4) PS1.B: Chemical Reactions • Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. (HS-PS1-4),(HS-PS1-5) • In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.	explanations of phenomena. (HS-PS1-1),(HS-PS1-2),(HS-PS1-3),(HS-PS1-5) Energy and Matter • In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. (HS-PS1-8) • The total amount of energy and matter in closed systems is conserved. (HS-PS1-7) • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS-PS1-4) Stability and Change • Much of science deals with constructing explanations of how things change and how they remain stable. (HS-PS1-6) Connections to Nature of Science Scientific Knowledge Assumes an Order and Consistency in Natural Systems • Science assumes the universe is a vast single system in which basic laws are consistent. (HS-PS1-7)
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the future. (HS-PS1-2) • Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-PS1-6) Asking Questions and Defining Problems • Analyze complex real-world problems by specifying criteria and constraints for successful solutions. (HS-ETS1-1) Using Mathematics and Computational Thinking • Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. (HS-ETS1-4) Constructing Explanations and Designing Solutions • Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-2) • Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)	(HS-PS1-6) • The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-2),(HS-PS1-7) PS1.C: Nuclear Processes • Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process. (HS-PS1-8) PS2.B: Types of Interactions • Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.(secondary to HS-PS1-1),(secondary to HS-PS1-3) ETS1.C: Optimizing the Design Solution • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (secondary to HS-PS1-6) ETS1.A: Defining and Delimiting Engineering Problems • Criteria and constraints also include satisfying any	
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	requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1) • Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1) ETS1.B: Developing Possible Solutions • When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3) • Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4)	
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	ETS1.C: Optimizing the Design Solution Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)	
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Chemistry



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Unit 4: MATTER AND ENERGY TRANSFORMATION IN LIVING SYSTEMS

Summary

Instructional Days: 20

How do organisms obtain and use the energy they need to live and grow?

In this unit of study, students construct explanations for the role of energy in the cycling of matter in organisms. They apply mathematical concepts to develop evidence to support explanations of the interactions of photosynthesis and cellular respiration and develop models to communicate these explanations. The crosscutting concept of *matter and energy* provides students with insights into the structures and processes of organisms. Students are expected to *develop and use models, plan and conduct investigations, use mathematical thinking, and construct explanations and design solutions* as they demonstrate proficiency with the disciplinary core ideas.

Student Learning Objectives

Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy. *[Clarification Statement: Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms. Examples of models could include diagrams, chemical equations, and conceptual models.] [Assessment Boundary: Assessment does not include specific biochemical steps.] (HS-LS1-5)*

Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy. *[Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.] [Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.] (HS-LS1-7)*

Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules. *[Clarification Statement: Emphasis is on using evidence from models and simulations to support explanations.] [Assessment Boundary: Assessment does not include the details of the specific chemical reactions or identification of macromolecules.] (HS-LS1-6)*

Unit Sequence

Part A: How does photosynthesis transform light energy into stored chemical energy?

Concepts	Formative Assessment
- The process of photosynthesis converts light energy to stored energy by converting carbon dioxide plus water into sugars plus released oxygen. - Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within a system.	

Unit Sequence	
Part B: How does cellular respiration result in a net transfer of energy?	
Concepts	Formative Assessment
- As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. - As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. - Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. - Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment. - Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems.	<i>Students who understand the concepts are able to:</i> - Construct an evidence-based model, to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed, resulting in a net transfer of energy. - Use their understanding of energy flow and conservation of energy to illustrate the inputs and outputs of the process of cellular respiration.
Unit Sequence	
Part C: How do elements of a sugar molecule combine with other elements and what molecules are formed?	
Concepts	Formative Assessment
- Sugar molecules contain carbon, hydrogen, and oxygen: Their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. - As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. - Changes of energy and matter in a system can be described in terms of energy and matter flows into, out	<i>Students who understand the concepts are able to:</i> - Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large, carbon-based molecules. - Construct and revise an explanation, based on valid and reliable evidence from a variety of sources (including models, theories, simulations, peer review) and on the assumption that theories and laws that describe the

of, and within that system.	natural world operate today as they did in the past and will continue to do so in the future, for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large, carbon based molecules. • Use evidence from models and simulations to support explanations for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large, carbon-based molecules.
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Teacher Professional Learning Resources

Instructional Resources

***Note-** The majority of the student sense-making experiences found at these links predate the NGSS. Most will need to be modified to include science and engineering practices, disciplinary core ideas, and cross cutting concepts. [The EQuIP Rubrics for Science](#) can be used as a blueprint for evaluating and modifying instructional materials.*

- American Association for the Advancement of Science: <http://www.aaas.org/programs>
- American Chemical Society: <http://www.acs.org/content/acs/en/education.html>
- Concord Consortium: Virtual Simulations: <http://concord.org/>
- International Technology and Engineering Educators Association: <http://www.iteaconnect.org/>
- National Earth Science Teachers Association: <http://www.nestanet.org/php/index.php>
- National Science Digital Library: <https://nsdl.oercommons.org/>
- National Science Teachers Association: <http://ngss.nsta.org/Classroom-Resources.aspx>
- North American Association for Environmental Education: <http://www.naaee.net/>
- Phet: Interactive Simulations <https://phet.colorado.edu/>
- Science NetLinks: <http://www.aaas.org/program/science-netlinks>

Appendix A: NGSS and Foundations for the Unit

Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy. *[Clarification Statement: Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms. Examples of models could include diagrams, chemical equations, and conceptual models.] [Assessment Boundary: Assessment does not include specific biochemical steps.] (HS-LS1-5)*

Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy. *[Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.] [Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.] (HS-LS1-7)*

Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules. *[Clarification Statement: Emphasis is on using evidence from models and simulations to support explanations.] [Assessment Boundary: Assessment does not include the details of the specific chemical reactions or identification of macromolecules.] (HS-LS1-6)*

The Student Learning Objectives above were developed using the following elements from the NRC document
A Framework for K-12 Science Education:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models - Use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-LS1-5),(HS-LS1-7) Constructing Explanations and Designing Solutions - Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the	LS1.A: Structure and Function - Systems of specialized cells within organisms help them perform the essential functions of life. (secondary to HS-LS1-4, HS-LS1-5, HS-LS1-6) - All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out most of the work of cells. (secondary to HS-LS1-4, HS-LS1-5, HS-LS1-6) - Multicellular organisms have a hierarchical structural organization, in which any one system is made up	Energy and Matter - Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS-LS1-5), (HS-LS1-6) - Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems. (HS-LS1-7)

future. (HS-LS1-6)	of numerous parts and is itself a component of the next level. (secondary to HS-LS1-4, HS-LS1-5, HS-LS1-6) - Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system. (secondary to HS-LS1-4, HS-LS1-5, HS-LS1-6) LS1.B: Growth and Development of Organisms - In multicellular organisms individual cells grow and then divide via a process called mitosis, thereby allowing the organism to grow. The organism begins as a single cell (fertilized egg) that divides successively to produce many cells, with each parent cell passing identical genetic material (two variants of each chromosome pair) to both daughter cells. Cellular division and differentiation produce and maintain a complex organism, composed of systems of tissues and organs that work together to meet the needs of the whole organism. (HS-LS1-4) LS1.C: Organization for Matter and Energy Flow in Organisms - The process of photosynthesis	
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	converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. (HS-LS1-5) • The sugar molecules thus formed contain carbon, hydrogen, and oxygen: their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. (HS-LS1-6) • As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. (HS-LS1-6),(HS-LS1-7) • As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment. (HS-LS1-7)	
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Chemistry



THE DIOCESE
of ALEXANDRIA

Unit 5: NUCLEAR CHEMISTRY

Summary

Instructional Days: 30

What happens in stars?

In this unit of study, energy and matter are studied further by investigating the processes of nuclear fusion and fission that govern the formation, evolution, and workings of the solar system in the universe. Some concepts studied are fundamental to science and demonstrate *scale, proportion, and quantity*, such as understanding how the matter of the world formed during the Big Bang and within the cores of stars over the cycle of their lives.

In addition, an important aspect of Earth and space sciences involves understanding the concept of *stability and change* while making inferences about events in Earth's history based on a data record that is increasingly incomplete the farther one goes back in time. A mathematical analysis of radiometric dating is used to comprehend how absolute ages are obtained for the geologic record.

The crosscutting concepts of *energy and matter, scale, proportion, and quantity*, and *stability and change* are called out as organizing concepts for this unit. Students are expected to demonstrate proficiency in *developing and using models; constructing explanations and designing solutions; using mathematical and computational thinking; and obtaining, evaluating, and communicating information*; and they are expected to use these practices to demonstrate understanding of the core ideas.

Student Learning Objectives

Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay. *[Clarification Statement: Emphasis is on simple qualitative models, such as pictures or diagrams, and on the scale of energy released in nuclear processes relative to other kinds of transformations.] [Assessment Boundary: Assessment does not include quantitative calculation of energy released. Assessment is limited to alpha, beta, and gamma radioactive decays.] (HS-PS1-8)*

Communicate scientific ideas about the way stars, over their life cycle, produce elements. *[Clarification Statement: Emphasis is on the way nucleosynthesis, and therefore the different elements created, varies as a function of the mass of a star and the stage of its lifetime.] [Assessment Boundary: Details of the many different nucleosynthesis pathways for stars of differing masses are not assessed.] (HS-ESS1-3)*

Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation. *[Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun's radiation varies due to sudden solar flares ("space weather"), the 11-year sunspot cycle, and non-cyclic variations over centuries.] [Assessment Boundary: Assessment does not include details of the atomic and subatomic processes involved with the sun's nuclear fusion.]* **(HS-ESS1-1)**

Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe. *[Clarification Statement: Emphasis is on the astronomical evidence of the red shift of light from galaxies as an indication that the universe is currently expanding, the cosmic microwave background as the remnant radiation from the Big Bang, and the observed composition of ordinary matter of the universe, primarily found in stars and interstellar gases (from the spectra of electromagnetic radiation from stars), which matches that predicted by the Big Bang theory (3/4 hydrogen and 1/4 helium).]* **(HS-ESS1-2)**

Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history. *[Clarification Statement: Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, moon rocks, and Earth's oldest minerals), the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces.]* **(HS-ESS1-6)**

Unit Sequence	
Part A: <i>Why is fusion considered the Holy Grail for the production of electricity? Why aren't all forms of radiation harmful to living things?</i>	
Concepts	Formative Assessments
- Nuclear processes, including fusion, fission, and radioactive decay of unstable nuclei, involve release or absorption of energy. - The total number of neutrons plus protons does not change in any nuclear process. - In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.	<i>Students who understand the concepts are able to:</i> - Develop models based on evidence to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay. - Use simple qualitative models based on evidence to illustrate the scale of energy released in nuclear processes relative to other kinds of transformations. - Develop models based on evidence to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of alpha, beta, and gamma radioactive decays.

Unit Sequence	
Part B: <i>How do stars produce elements?</i>	
Concepts	Formative Assessments
- The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth. Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode. - In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.	<i>Students who understand the concepts are able to:</i> - Communicate scientific ideas in multiple formats (including orally, graphically, textually, and mathematically) about the way stars, over their life cycles, produce elements. - Communicate scientific ideas about the way nucleosynthesis, and therefore the different elements it creates, vary as a function of the mass of a star and the stage of its lifetime. - Communicate scientific ideas about how in nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

Unit Sequence	
Part C: <i>Is the life span of a star predictable?</i>	
Concepts	Formative Assessments
- The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years. - Nuclear fusion processes in the center of the sun release the energy that ultimately reaches Earth as radiation. - The significance of the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth is dependent on the scale, proportion, and quantity at which it occurs.	<i>Students who understand the concepts are able to:</i> - Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core in releasing energy that eventually reaches Earth in the form of radiation. - Develop a model based on evidence to illustrate the relationships between nuclear fusion in the sun's core and radiation that reaches Earth.

Unit Sequence	
Part D: <i>If there was nobody there to Tweet about it, how do we know that there was a Big Bang?</i>	
Concepts	Formative Assessment
- The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth. - The Big Bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gases, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe. - Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode. - Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities. - Energy cannot be created or destroyed, only moved between one place and another place, between objects	<i>Students who understand the concepts are able to:</i> - Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe. - Construct an explanation of the Big Bang theory based on the astronomical evidence of the red shift of light from galaxies as an indication that the universe is currently expanding, the cosmic microwave background as the remnant radiation from the Big Bang, and the observed composition of ordinary matter of the universe, primarily found in stars and interstellar gases (from the spectra of electromagnetic radiation from stars). - Construct an explanation based on valid and reliable evidence that energy in the universe cannot be created or destroyed, only moved between one place and another place, between objects and/or fields, or between systems.

and/or fields, or between systems. • Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. • Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and will continue to do so in the future. • Science assumes the universe is a vast single system in which basic laws are consistent. • A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.	
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Unit Sequence	
Part E: <i>How can chemistry help us to figure out ancient events?</i>	
Concepts	Formative Assessment
• Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history. • Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials. • Much of science deals with constructing explanations of how things change and how they remain stable.	<i>Students who understand the concepts are able to:</i> • Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history. • Use available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. • Apply scientific reasoning to link evidence from ancient Earth materials, meteorites, and other planetary surfaces to claims about Earth's formation and early history, and assess the extent to which the reasoning and data support the explanation or conclusion. • Use available evidence within the solar system to construct explanations for how Earth has changed and how it remains stable.

Teacher Professional Learning Resources

Instructional Resources

***Note-** The majority of the student sense-making experiences found at these links predate the NGSS. Most will need to be modified to include science and engineering practices, disciplinary core ideas, and cross cutting concepts. [The EQuIP Rubrics for Science](#) can be used as a blueprint for evaluating and modifying instructional materials.*

- American Association for the Advancement of Science: <http://www.aaas.org/programs>
- American Chemical Society: <http://www.acs.org/content/acs/en/education.html>
- Concord Consortium: Virtual Simulations: <http://concord.org/>
- International Technology and Engineering Educators Association: <http://www.iteaconnect.org/>
- National Earth Science Teachers Association: <http://www.nestanet.org/php/index.php>
- National Science Digital Library: <https://nsdl.oercommons.org/>
- National Science Teachers Association: <http://ngss.nsta.org/Classroom-Resources.aspx>
- North American Association for Environmental Education: <http://www.naaee.net/>
- Phet: Interactive Simulations <https://phet.colorado.edu/>
- Science NetLinks: <http://www.aaas.org/program/science-netlinks>

Appendix A: NGSS and Foundations for the Unit

Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay. *[Clarification Statement: Emphasis is on simple qualitative models, such as pictures or diagrams, and on the scale of energy released in nuclear processes relative to other kinds of transformations.] [Assessment Boundary: Assessment does not include quantitative calculation of energy released. Assessment is limited to alpha, beta, and gamma radioactive decays.]* **(HS-PS1-8)**

Communicate scientific ideas about the way stars, over their life cycle, produce elements. *[Clarification Statement: Emphasis is on the way nucleosynthesis, and therefore the different elements created, varies as a function of the mass of a star and the stage of its lifetime.] [Assessment Boundary: Details of the many different nucleosynthesis pathways for stars of differing masses are not assessed.]* **(HS-ESS1-3)**

Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation. *[Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun's radiation varies due to sudden solar flares ("space weather"), the 11-year sunspot cycle, and non-cyclic variations over centuries.] [Assessment Boundary: Assessment does not include details of the atomic and subatomic processes involved with the sun's nuclear fusion.]* **(HS-ESS1-1)**

Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe. *[Clarification Statement: Emphasis is on the astronomical evidence of the red shift of light from galaxies as an indication that the universe is currently expanding, the cosmic microwave background as the remnant radiation from the Big Bang, and the observed composition of ordinary matter of the universe, primarily found in stars and interstellar gases (from the spectra of electromagnetic radiation from stars), which matches that predicted by the Big Bang theory (3/4 hydrogen and 1/4 helium).]* **(HS-ESS1-2)**

Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history. *[Clarification Statement: Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, moon rocks, and Earth's oldest minerals), the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces.]* **(HS-ESS1-6)**

The Student Learning Objectives above were developed using the following elements from the NRC document
A Framework for K-12 Science Education:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9-12 builds on K-8 and	PS1.C: Nuclear Processes	Energy and Matter In nuclear processes, atoms are not

progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. - Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-PS1-8),(HS-ESS1-1) Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. - Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-ESS1-2) - Apply scientific reasoning to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. (HS-ESS1-6) Using Mathematical and Computational Thinking	- Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process. (HS-PS1-8) - Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials. (secondary (HS-ESS1-6)) ESS1.A: The Universe and Its Stars - The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years. (HS-ESS1-1) - The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth. (HS-ESS1-2),(HS-ESS1-3) - The Big Bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gases, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe. (HS-ESS1-2) - Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a	conserved, but the total number of protons plus neutrons is conserved. (HS-ESS1-3), (HS-PS1-8), (HS-ESS1-1) - Energy cannot be created or destroyed—only moved between one place and another place, between objects and/or fields, or between systems. (HS-ESS1-2) Scale, Proportion, and Quantity - The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (HS-ESS1-1) - Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth). (HS-ESS1-4) - In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. Stability and Change - Much of science deals with constructing explanations of how things change and how they remain stable. (HS-ESS1-6) Connections to Engineering, Technology, and Applications of Science Interdependence of Science, Engineering, and Technology - Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with
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- Mathematical and computational thinking in 9–12 builds on K–8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. - Use mathematical or computational representations of phenomena to describe explanations. (HS-ESS1-4) Obtaining, Evaluating, and Communicating Information - Obtaining, evaluating, and communicating information in 9–12 builds on K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs. (HS-ESS1-6) - Communicate scientific ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (HS-ESS1-3)	supernova stage and explode. (HS-ESS1-2),(HS-ESS1-3) PS3.D: Energy in Chemical Processes and Everyday Life - Nuclear Fusion processes in the center of the sun release the energy that ultimately reaches Earth as radiation. (secondary) (HS-ESS1-1) PS4.B: Electromagnetic Radiation - Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities.(secondary)HS-ESS1-2) ESS1.B: Earth and the Solar System - Kepler’s laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system. (HS-ESS1-4) ESS1.C: The History of Planet Earth - Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth’s formation and early history.	wide ranges of expertise. (HS-ESS1-2),(HS-ESS1-4) Connections to Nature of Science Scientific Knowledge Assumes an Order and Consistency in Natural Systems - Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. (HS-ESS1-2) - Science assumes the universe is a vast single system in which basic laws are consistent. (HS-ESS1-2) Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena - A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. (HS-ESS1-2)
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Chemistry



THE DIOCESE
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Unit 6: HUMAN IMPACT: THE CHEMISTRY OF SUSTAINABILITY

Summary

Instructional Days: 30

How do Earth's geochemical processes and human activities affect each other?

In this unit of study, students use *cause and effect* to *develop models and explanations* for the ways that feedbacks among different Earth systems control the appearance of Earth's surface. Central to this is the tension between internal systems, which are largely responsible for creating land at Earth's surface (e.g., volcanism and mountain building), and the sun-driven surface systems that tear down the land through weathering and erosion. Students begin to examine the ways that human activities cause feedbacks that create changes to other systems. Students understand the *system interactions* that control weather and climate, with a major emphasis on the mechanisms and implications of climate change. Students model the flow of energy and matter between different components of the weather system and how this affects chemical cycles such as the carbon cycle. Engineering and technology figure prominently here, as students use mathematical thinking and the analysis of geoscience data to examine and construct solutions to the many challenges facing long-term human sustainability on Earth. Here students will use these geoscience data to explain climate change over a wide range of timescales, including over one to ten years: large volcanic eruption, ocean circulation; ten to hundreds of years: changes in human activity, ocean circulation, solar output; tens of thousands to hundreds of thousands of years: changes to Earth's orbit and the orientation of its axis; and tens of millions to hundreds of millions of years: long-term changes in atmospheric composition).

Student Learning Objectives

Use a **model** to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

[Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.] [Assessment Boundary: Assessment of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.] (HS-ESS2-4)

Develop a **quantitative model** to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere. *[Clarification Statement: Emphasis is on modeling biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere (including humans), providing the foundation for living organisms.] (HS-ESS2-6)*

Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants. *[Clarification Statement: See Three-Dimensional Teaching and Learning Section for examples.] (HS-ETS1-1)*

Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. *[Note: See Three-Dimensional Teaching and Learning Section for examples.]* (HS-ETS1-2)

Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. *[Note: See Three-Dimensional Teaching and Learning Section for examples.]* (HS-ETS1-3)

Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem. *[Note: See Three-Dimensional Teaching and Learning Section for examples.]* (HS-ETS1-4)

Unit Sequence	
Part A: <i>What happens if we change the chemical composition of our atmosphere?</i>	
Concepts	Formative Assessment
- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space. - Cyclical changes in the shape of Earth's orbit around the sun, together with changes in the tilt of the planet's axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on the earth. These phenomena cause a cycle of ice ages and other gradual climate changes. - The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles. - Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. - Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. - Science arguments are strengthened by multiple lines of evidence supporting a single explanation.	<i>Students who understand the concepts are able to:</i> - Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. - Use empirical evidence to differentiate between how variations in the flow of energy into and out of Earth's systems result in climate changes. - Use multiple lines of evidence to support how variations in the flow of energy into and out of Earth's systems result in climate changes.

Unit Sequence	
Part B: How does carbon cycle among the hydrosphere, atmosphere, geosphere, and biosphere?	
Concepts	Formative Assessment
- Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. - Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. - The total amount of energy and matter in closed systems is conserved. - The total amount of carbon cycling among and between the hydrosphere, atmosphere, geosphere, and biosphere is conserved.	<i>Students who understand the concepts are able to:</i> - Develop a model based on evidence to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere. - Develop a model based on evidence to illustrate the biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere, providing the foundation for living organisms.

Teacher Professional Learning Resources

Instructional Resources

***Note-** The majority of the student sense-making experiences found at these links predate the NGSS. Most will need to be modified to include science and engineering practices, disciplinary core ideas, and cross cutting concepts. [The EQuIP Rubrics for Science](#) can be used as a blueprint for evaluating and modifying instructional materials.*

- American Association for the Advancement of Science: <http://www.aaas.org/programs>
- American Chemical Society: <http://www.acs.org/content/acs/en/education.html>
- Concord Consortium: Virtual Simulations: <http://concord.org/>
- International Technology and Engineering Educators Association: <http://www.iteaconnect.org/>
- National Earth Science Teachers Association: <http://www.nestanet.org/php/index.php>
- National Science Digital Library: <https://nsdl.oercommons.org/>
- National Science Teachers Association: <http://ngss.nsta.org/Classroom-Resources.aspx>
- North American Association for Environmental Education: <http://www.naaee.net/>
- Phet: Interactive Simulations <https://phet.colorado.edu/>
- Science NetLinks: <http://www.aaas.org/program/science-netlinks>

Appendix A: NGSS and Foundations for the Unit

Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. *[Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.] [Assessment Boundary: Assessment of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.] (HS-ESS2-4)*

Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere. *[Clarification Statement: Emphasis is on modeling biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere (including humans), providing the foundation for living organisms.] (HS-ESS2-6)*

Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants. *[Clarification Statement: See Three-Dimensional Teaching and Learning Section for examples.] (HS-ETS1-1)*

Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. *[Note: See Three-Dimensional Teaching and Learning Section for examples.] (HS-ETS1-2)*

Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. *[Note: See Three-Dimensional Teaching and Learning Section for examples.] (HS-ETS1-3)*

Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem. *[Note: See Three-Dimensional Teaching and Learning Section for examples.] (HS-ETS1-4)*

The Student Learning Objectives above were developed using the following elements from the NRC document
A Framework for K-12 Science Education:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models - Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-ESS2-1),(HS-ESS2-3),(HS-ESS2-6) - Use a model to provide mechanistic	ESS1.B: Earth and the Solar System Cyclical changes in the shape of Earth's orbit around the sun, together with changes in the tilt of the planet's axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of	Cause and Effect Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-ESS2-4) Energy and Matter

accounts of phenomena. (HS-ESS2-4) Asking Questions and Defining Problems - Analyze complex real-world problems by specifying criteria and constraints for successful solutions. (HS-ETS1-1) Using Mathematics and Computational Thinking - Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. (HS-ETS1-4) Constructing Explanations and Designing Solutions - Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)	sunlight falling on the earth. These phenomena cause a cycle of ice ages and other gradual climate changes. (<i>secondary to HS-ESS2-4</i>) ESS2.A: Earth Materials and Systems - The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles. (HS-ESS2-4) ESS2.D: Weather and Climate - The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space. (HS-ESS2-4) - Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. (HS-ESS2-6) - Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. (HS-ESS2-6),(HS-	- The total amount of energy and matter in closed systems is conserved. (HS-ESS2-6) Systems and System Models - Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. (HS-ETS1-4) <i>Connections to Engineering, Technology, and Applications of Science</i> Influence of Science, Engineering, and Technology on Society and the Natural World - New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-1) (HS-ETS1-3) <i>Connections to Nature of Science</i> Scientific Knowledge is Based on Empirical Evidence - Science arguments are strengthened by multiple lines of evidence supporting a single explanation. (HS-ESS2-4)
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	ESS2-4) ETS1.A: Defining and Delimiting Engineering Problems • Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1) • Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1) ETS1.B: Developing Possible Solutions • When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3) • Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most	
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	efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4) ETS1.C: Optimizing the Design Solution • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)	
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