Support for NGSS in A Natural Approach to Chemistry

This third edition of *A Natural Approach to Chemistry* has been revised and updated to provide dedicated support to the Next Generation Science Standards (NGSS, https://www.nextgenscience.org/). The Standards were developed from *A Framework for K-12 Science Education: Practices, Core Ideas, and Crosscutting Concepts* (Framework)[1]. The *Framework* recommends science education in grades K-12 be built around three major dimensions: scientific and engineering practices; crosscutting concepts that unify the study of science and engineering through their common application across fields; and core ideas in the major disciplines of natural science.

Core disciplinary ideas (DCI) are the fundamental scientific ideas that form the content of an NGSS curriculum. They cover four domains: physical science, life science, earth and space science, as well as engineering, technology, and applications of science. The eight practices of science and engineering (SEP) are what students do to make sense of phenomena and that scientists and engineers use to investigate the world and design and build systems. There are seven crosscutting concepts (CCC) that bridge disciplinary boundaries, uniting core ideas throughout the fields of science and engineering. Their purpose is to help students deepen their understanding of the disciplinary core ideas, and develop a coherent and scientifically based view of the world.

The high school performance expectations for chemistry can be found in the "Physical Sciences" group, where they are combined with the performance expectations for physics. Those dealing with what would be covered in a high school chemistry class can generally be found in HS-PS1, Matter and Atoms, and HS-PS3, Energy. Unlike the high school biology and earth sciences which provide sufficient depth and breadth for a full year's instruction, the chemistry-oriented standards themselves do not provide enough content for a full year course; and a scope and sequence driven solely by the NGSS would likely omit traditional content such as the gas laws, stoichiometry, some electrochemistry, organic chemistry and more.

Therefore, the approach the authors have taken in this new edition is to provide support for the NGSS where they exist, to incorporate the use of phenomena and three dimensional teaching and learning throughout the program , and to include these traditional topics in order to support a full year course in chemistry at the high school level, as it is currently taught in much of the country. Additionally, as it may be of interest to some teachers who teach an integrated course of study, the authors have included support for selected life and earth science standards where they occur; for example, chapter 18 (Chemistry of Living Systems) provides partial support for HS-LS1-5, 1-6, and 1-7, with its coverage of the light and dark reactions of photosynthesis, the chemistry of proteins, fats, and carbohydrates, and the structure and function of DNA. Chapter 19 provides partial support for HS-ESS2-4, 2-5, and 3-4 with a discussion of the chemistry of high altitude interactions that lead to global warming and climate change and the atmospheric cycling of carbon, nitrogen and other elements is supported.

Each chapter of the student book begins with a Getting Started section that sets out the anchor phenomena and provides teachers with suggestions for incorporating student questions. Chapters end with "Chemistry Connections, which are used to reinforce content from the nature of science and Cross Cutting Concepts (CCC) associated with the PEs addressed. Sections of the student book provide support for the Disciplinary Core Ideas (DCIs), while the more than 60 lab investigations provide support for the practices of Science and Engineering Practices (SEP) and new open-ended labs have been added to give students practice in designing solutions to engineering problems (ETS). Of course, these three-dimensional elements are woven throughout the program, not confined to these specific locations in the course.

[1] NRC (2012). A Framework for K-12 Science Education: Practices, Core Ideas, and Crosscutting Concepts. Washington, DC: National Academy Press.

The following table provides an overview of the NGSS support, by chapter. More NGSS coverage detail is provided in the individual chapter sections that follow in this Teacher Edition.

NAC CHAPTER	NGSS SUPPORT				
	PE(s)	DCI	SEP	CCC	CC ELA/MATH
1 The Science of Chemistry	HS-PS3-2	PS3.A	Developing and using models	Energy and matter	SL.11-12.5* MP.2* MP.4*
2 Matter and Atoms	HS-PS1-1 HS-PS1-3	PS1.A, PS1.B	Developing and using models Planning and carrying out Investigations	Patterns	RST.9-10.7* WHST.9-12.9* SL.11-12.5* HSN-Q.A.1* HSN-Q.A.3*
3 Temperature, Energy and Heat	HS-PS3-1, HS-PS3-2, HS-PS3-4	PS3.A, PS3.B	Developing and using models Planning and carrying out investigations	Energy and matter Systems and system models	RST.11-12.1* SL.11-12.5* WHST.9-12.2* MP.2* MP.4*
4 Physical and Chemical Change	HS-PS1-2 HS-PS1-4	PS1.A, PS1.B	Developing and using models	Energy and matter Patterns	WHST.9-12.2 SL.11-12.5 MP.4*
5 The Structure of the Atom	HS-PS1-1 HS-PS-4-3	PS1.A, PS4.B	Developing and using models Engaging in argument from evidence	Patterns Systems and system models	RST.9-10.7* RST.11-12.1* HSN-Q.A.2* HSA-SSE.A.1*
6 Elements and the Periodic Table	HS-PS1-1, HS-PS1-2	PS1.A	Developing and using models	Patterns	RST.9-10.7* WHST.9-12.7* HSN-Q.A.1*
7 Bonding	HS-PS1-1, HS-PS1-2	PS1.A, PS1.B	Developing and using models Constructing and revising explanations	Patterns	RST.9-10.7* WHST.9-12.5* MP.2*
8 Compounds and Mixtures	HS-PS1-3	PS1.A, PS1.B	Planning and conducting investigations	Patterns	WHST.9-12.9* HSN-Q.A.3*
9 Water and Solutions	HS-PS1-3 HS-PS3-2 HS-PS3-3	PS1.B, PS3.A	Planning and carrying out investigations Constructing explanations and designing solutions	Patterns Energy and matter	WHST.9-12.7* WHST.9-12.9* HSN-Q.A.1* HSN-Q.A.3* MP.2*
10 Chemical Reactions	HS-PS1-7 HS-PS3-1	PS1.B PS3.B	Using mathematics and computational thinking	Energy and matter Systems and system models	MP.2 HSN-Q.A.1 HSN-Q.A.2 HSN-Q.A.3
11 Stoichio-metry	HS-PS1-7	PS1.B	Using mathematics and computational thinking	Energy and matter	MP.2

** Partially supported*

NAC CHAPTER	NGSS SUPPORT				
	PE(s)	DCI	SEP	CCC	CC ELA/MATH
12 Reaction Rates and Equilibrium	HS-PS1-4, HS-PS1-5, HS-PS1-6	PS1.A, PS1.B, ETS1.C	Developing and using models Constructing explanations and designing solutions	Energy and Matter Stability and change	SL.11-12.5* WHST.9-12.7* MP.2* MP.4*
13 Acids and Bases	HS-PS1-2* (13.3 only)	PS1.A	Constructing explanations and designing solutions	Patterns	
14 Gases	Content from this chapter is not explicitly referenced in NGSS				
15 Electro-chemistry	HS-PS3-3	PS3.B PS3.D ETS1.A	Constructing explanations and designing solutions	Energy and matter	WHST.9-12.7* HSN-Q.A.3*
16 Solids and Liquids	HS-PS1-3*	PS1.A	Planning and conducting investigations	Patterns	WHST.9-12.9* MP.2*
17 Organic Chemistry	HS-LS1-6*	LS1.C*	Constructing explanations and designing solutions	Energy and matter	RST.11-12.1* WHST.9-12.2* WHST.9-12.9
18 The Chemistry of Living Systems	HS-LS1-1* HS-LS1-5* HS-LS1-6* HS-LS1-7*	LS1.A* LS1.C*	Developing and using models Constructing explanations and designing solutions	Energy and matter Structure and function	SL.11-12.5*
19 The Chemistry of the Earth	HS-ESS2-4* HS-ESS2-5* HS-ESS3-4*	ESS2.C* ESS2.D* ESS3.C*	Developing and using models Planning and carrying out investigations Constructing explanations and designing solutions	Cause and effect Stability and change Structure and function	SL.11-12.5* RST.11-12.1* WHST.9-12.7* MP.2*
20 Nuclear Chemistry and Radio-activity	HS-PS1-8	PS1.C	Developing and using models	Energy and matter	MP.4*
21 The Chemistry of the Solar System	HS-ESS1-1* HS-ESS1-2* HS-ESS1-3*	ESS1.A* ESS1.C* PS3.D*	Developing and using models Constructing explanations and designing solutions Obtaining, evaluating and communicating information	Scale, proportion and quantity Energy and matter Developing and using models Constructing explanations and designing solutions	RST.11-12.1* RST.11-12.2* MP.2, MP.4, * HSN-Q.A.1, * HSN_Q.A.2*

** Partially supported*

Use of Phenomena in A Natural Approach to Chemistry

A phenomenon is simply an observable event that we can use our science knowledge to explain or predict. Engineers design solutions to problems that arise from phenomena. Phenomena provide context for the work of both scientists and engineers. Student inquiry can be driven by using a carefully chosen phenomena. Phenomena add relevance to the science classroom showing students science in their own world. A good phenomenon is observable, interesting, complex, and aligned to the appropriate standard. Use of phenomena helps students identify answers for "why they need to learn this," and shifts from learning about a topic to figuring out why something happens. The focus should not be on the phenomenon itself, but on the student generated questions that guide learning and teaching. The same phenomenon might be used in very different ways, depending on the student audience and grade level, to drive teaching and learning. Use of phenomena provides critical access for English learners or for students from historically underrepresented groups. There is a difference between anchoring phenomena, which serve as the focus for a unit, and investigative phenomena that might serve individual lessons.

Thinking about the use of phenomena has evolved since the public release of NGSS in 2013, as seen by the following table[2]:

EARLY THINKING ABOUT PHENOMENA	RECENT THINKING ABOUT USING PHENOMENA TO REALIZE THE POWER OF NGSS
Anything students are interested in would make a good phenomenon.	Students need deep engagement with the material to generate an explanation of the phenomenon using the three elements of the PE (DCI, SEP, CCC).
Explanations are examples of phenomena.	Phenomena (e.g., sunburn, vision loss) are a specific example of a general process; they are what can be experienced or documented.
Phenomena need to be flashy, fun, or using hands on to be engaging.	Authentic engagement can occur without fun or flash; instead engagement is determined by how students create real opportunities for learning.
Phenomena are just for the initial hook.	Phenomena can drive a lesson; use of a phenomena in this way drives deeper learning.
Phenomena need to be questions.	Phenomena are observable occurrences that are used to generate science questions or problems that drive learning.
Student engagement is nice but not required.	Engagement is an important access and equity issue. A good phenomenon builds on everyday experiences available to all students.
Phenomena are good to bring in after students develop the science ideas so they can apply what they learned.	Many students have trouble applying decontextualized content or ideas; anchoring the development of ideas in phenomena helps students build more usable knowledge.

Each chapter begins with an overview and with a short representation of a hands-on activity that can be used to engage students in the anchor phenomena and main themes. For example, in chapter 2, students investigate a reaction between sodium borate and a glue solution[3] as a focus phenomena which leads to students brainstorming questions they have about the diversity of matter and how new substances are formed – the main themes for the chapter. Students learn chemistry by doing chemistry, exploring the science and engineering practices (SEP) as they work through more than 60 lab investigations - many of which feature the Lab Hub(R), an advanced system that incorporates an RGB spectrophotometer, measures temperature and voltage, and a safe, control point heating system that eliminates the need for a bunsen burner. The Lab Hub (R) can be controlled via bluetooth connection to most smartphones, tablets, and laptops. The 5E model (add reference) is used throughout, and each chapter shows a detailed treatment of every phase of the model. This is described later in this Introduction.

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2 https://www.nextgenscience.org/sites/default/files/Using%20Phenomena%20in%20NGSS.pdf)

3 they can read about it, watch a video or do the mini-lab themselves

Examples of Phenomena in the Student Book

This is not an exhaustive list. It is prepared to give teachers some support for using phenomena in teaching chemistry. It is also encouraged to make connections to related local phenomena in your community when possible. Each chapter of the student book begins with 3-4 driving questions which also focus on phenomena developed in the chapter. The Lab Investigation Manual (LIM) is another source of support for this practice.

CHAPTER	PHENOMENA (STATED AS QUESTIONS)
1	When a tree grows, where does the mass of the tree come from? (1.1)
	What is fire? Is it chemical, matter, and/or energy? (1.1)
	Why does a bottle collapse if you remove the air from it? (1.2)
	What happens to the energy in hot coffee as it cools? (1.3)
2	Is the "stuff" that makes up your body the same "stuff that makes up everything else on Earth? (Getting Started; see also 6.1)
	How can the glue/borax mixture change its properties after mixing, going from liquid to solid? (Getting Started)
	How do we get millions of substances from mixing 90+ elements? (2.2)
	How can the same elements combine to form different compounds with the same chemical formula? (2.2)
	How can chemicals that are toxic combine to form compounds that are not? (Chemical Connections)
3	What is different about a substance when it is hot compared to when it is cold? (Getting Started)
	Why do hot things feel hot and cold things feel cold? (3.1)
	Why don't cold things get colder and hot things get hotter? (3.2)
	Why does water have a much higher specific heat than otherwise "strong" materials like steel? (3.2)
	How can water exist as ice and in liquid form at 0 degrees C? (3.3)
	Why does the boiling temperature of water decrease with altitude? (3.3)
4	Why are there only three kinds of electrical charge, neutral, positive, and negative ? (4.1)
	Why do chemical reactions occur? (4.2)
	Why do some chemical reactions liberate heat and others absorb heat? (4.2)
5	Why do elements have a characteristic emission spectra? (5.1)
	Where do all the elements come from? (5.1)
	How can the electron behave like both a wave and a particle? (5.2)
6	Why do compounds form? Why do elements bond with only certain other elements? (6.2)
	Why do elements in the same column –but not row –of the periodic table have similar properties? (6.2)
7	Why do different kinds of bonds form? (7.1)
	How can we use the periodic table to predict what will bond? (7.2)
8	If sugar and salt look alike, why do they have such different properties? (8.1)
	Why are diamonds so hard? (8.2)
	How do water bugs "walk" on water? (8.3)
	Why is solid water less dense than liquid water? (8.3)

CHAPTER	PHENOMENA (STATED AS QUESTIONS)
9	Why does water dissolve so many different substances? (9.1)
	Why do some solutions support an electric current, while others do not? (9.1)
	Why does ice melt when you sprinkle salt on it? (9.3)
10	Why does rusting generate heat? (Getting Started)
	Why are some compounds soluble in water while others aren't? (10.2)
11	If trees remove carbon dioxide from the atmosphere, why can't we just plant more trees to get out of the global warming crisis? (Chemical Connections)
12	Can chemical reactions really go "backward?" (Getting Started)
	Why are some chemical reactions fast while others are slow? (12.1)
	Why do chemical systems shift to offset stress? (12.2)
	How can substances speed up a chemical reaction without being used up? (12.4)
13	How can your stomach contain a chemical strong enough to burn skin and dissolve metals? (Getting Started)
	How can water act as both an acid and a base? (13.1)
	How can soil pH affect the color of flowers? (Chemical Connections)
14	Why do my tires get flat on a very cold day? Why won't my vacuum cleaner work on the moon? (Getting Started)
	Why do different gases have the same pressure at the same temperature? (14.1)
	Why is there really no such thing as suction? (14.2)
	How can training at altitude help increase endurance for athletes who compete at sea level? (Chemistry Connections)
15	How do batteries work? (Getting Started)
	Why do some metals rust while others do not? (Getting Started)
	How can you get electricity from a lemon? (15.1)
	Why won't the same two metals work as electrodes for a simple battery? (15.1)
	How do catalytic converters work in auto exhaust systems? (Chemical Connections)
16	Can you really melt metal with just the heat of your hand? (Getting Started)
	Why are the properties of some solids different from others? (16.1, 16.2)
	How can adding such a small amount of carbon make iron so much stronger? (16.3)
	How do insects "walk" on water? (16.4)
17	Why do isomers of the same carbon molecule have such different properties? (17.1)
	How do hydrogels like sodium polyacrylate absorb so much water? (Chemical Connections)
18	Why are some fats and carbohydrates better for you than others? (18.1)
	How does eating too much sugar or starch result in your body producing fats? (18.1)
	How do plants make their own food? Why can't animals do this? (18.2)
	How can DNA possibly carry all the information your body needs to grow, live, repair itself, create offspring, and more? (18.4)

CHAPTER	PHENOMENA (STATED AS QUESTIONS)
19	How do chemical reactions in the atmosphere affect life? (19.1)
	How can carbon dioxide affect the global climate on Earth? (19.1)
	How are elements and molecules recycled on Earth? (19.1, 19.2)
	If Earth is made of mainly the same elements, why are the layers different? (19.3)
	Where do rocks come from? (19.3)
20	How are nuclear reactions different from chemical reactions? (20.1)
	Why are only some elements radioactive? (20.2)
	How can radioactive dating be used to give the approximate age of objects? (20.3)
	Why is nuclear fusion preferred to nuclear fission as an energy source? (20.4)
	How does radiation damage the human body? (20.5)
21	Where did the Sun and Solar System (and the rest of the universe) come from? (21.1)
	Where does the Sun and stars get their energy from? (21.1)
	If most of the universe is made of hydrogen and helium, where do the heavier elements come from? (21.1)
	Is it possible for life to exist elsewhere in the universe? If so, what conditions are required? (21.3)

Working With the Crosscutting Concepts

The *Framework* identifies seven crosscutting concepts that bridge disciplinary boundaries, uniting core ideas throughout the fields of science and engineering. Their purpose is to help students deepen their understanding of the disciplinary core ideas (pp. 2 and 8), and develop a coherent and scientifically based view of the world. (NGSS Appendix G: Crosscutting Concepts, p. 83.) The seven crosscutting concepts presented in Chapter 4 of the Framework are as follows:

1. Patterns*. Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.

2. Cause and effect: Mechanism and explanation. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.

3. Scale, proportion, and quantity. In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.

4. Systems and system models*. Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.

5. Energy and matter*: Flows, cycles, and conservation. Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.

6. Structure and function. The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.

7. Stability and change*. For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

Crosscutting concepts are for *all* students. "Crosscutting concepts raise the bar for students who have not achieved at high levels in academic subjects and are often assigned to classes that emphasize "the basics," which in science may be taken to provide primarily factual information and lower order thinking skills. Consequently, it is essential that all students engage in using crosscutting concepts, which could result in leveling the playing field and promoting deeper understanding for all students." (NGSS Appendix G: Crosscutting Concepts, p.3). Students will generally find examples of CCC in the Chemistry Connections section at the end of each chapter, although these connections are not explicitly labeled as such.

*These crosscutting concepts are found in HS-PS1 and HS-PS3, and are therefore featured in *A Natural Approach to Chemistry*.

Based on the NGSS Standards from the high school physical sciences that are best supported in *A Natural Approach to Chemistry*, namely, HS-PS-1 and HS-PS3, covering matter and energy, respectively, the relevant crosscuts associated with these standards are:

- Energy and matter
- Patterns
- Stability and change
- Systems and system models

The following prompts can help support students to identify and better understand the CCC in *A Natural Approach to Chemistry*. They are adapted from Graphic Organizer Tools to Support the Crosscutting Concepts, Secondary, by J Peacock and A Peacock.

Energy and Matter

Energy and matter are basic to any systems model, whether of a natural or a designed system. Systems are described in terms of matter and energy. Often the focus of an investigation is to determine how energy or matter flows through the system, or in the case of engineering to modify the system, so a given energy input results in a more useful energy output. (from NGSS, Appendix G, p. 12).

PROGRESSION ACROSS THE GRADES	PERFORMANCE EXPECTATION FROM THE NGSS
In grades 9-12, students learn that the total amount of energy and matter in closed systems is conserved. They can describe changes of energy and matter in a system in terms of energy and matter flows into, out of, and within that system. They also learn that energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems. Energy drives the cycling of matter within and between systems. In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.	HS-PS1-8. 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.

The following prompts can help students focus on Energy and Matter in the unit of study:

What phenomenon are you studying?

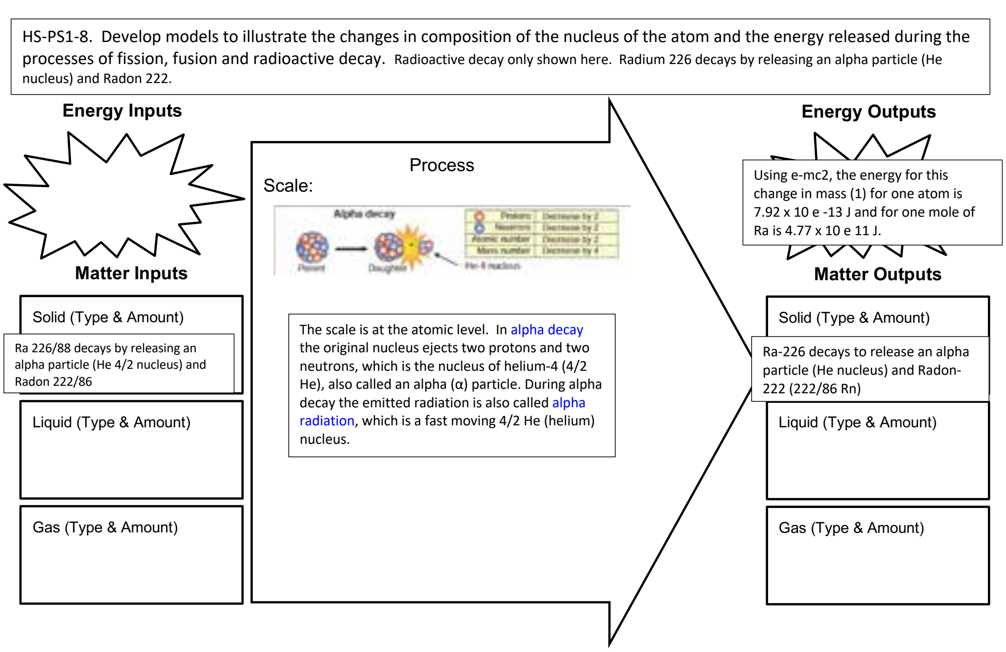
- What are the energy INPUTS? The energy OUTPUTS?
- What are the matter inputs and outputs? List the types and amounts for solids, liquids, and gases. See below:

ENERGY AND/OR MATTER INPUT → ENERGY AND/OR MATTER OUTPUT

- Does your evidence show that matter and/or energy were conserved? Explain.
- Is the movement of matter connected to the flow of energy in the process? Explain.
- Are energy and/or matter transformed during the process? For example, is the chemical energy in bonds of reactants absorbed or released during the reaction?

Here is an example of Energy and Matter from Chapter 20 in NAC.

Applying **Matter & Energy** to the Phenomenon of Nuclear Processes



Patterns

Patterns stand alone because patterns are a pervasive aspect of all fields of science and engineering. When first exploring a new phenomenon, children will notice similarities and differences leading to ideas for how they might be classified. The existence of patterns naturally suggests an underlying cause for the pattern. For example, observing snowflakes are all versions of six-side symmetrical shapes suggests something about how molecules pack together when water freezes; or, when repairing a device a technician would look for a certain pattern of failures suggesting an underlying cause. Patterns are also helpful when interpreting data, which may supply valuable evidence in support of an explanation or a particular solution to a problem. (from NGSS, Appendix G, p. 11).

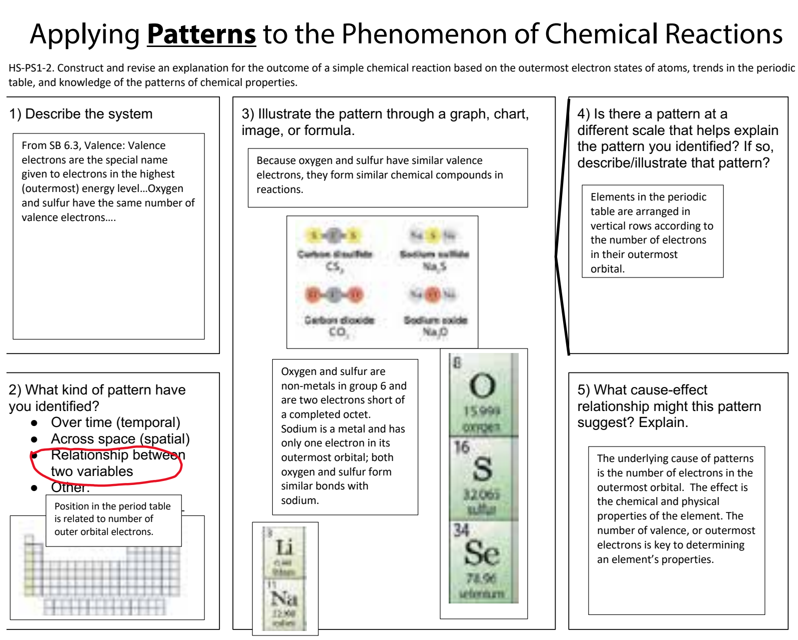
PROGRESSION ACROSS THE GRADES	PERFORMANCE EXPECTATION FROM THE NGSS
In grades 9-12, students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. They recognize classifications or explanations used at one scale may not be useful or need revision using a different scale; thus requiring improved investigations and experiments. They use mathematical representations to identify certain patterns and analyze patterns of performance in order to reengineer and improve a designed system.	HS-PS1-2. 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.

The following prompts can help students focus on Patterns in the unit of study:

What phenomenon are you studying?

- Describe the system and its boundaries or "edges"
- Do you see a pattern? If so, what kind of pattern? (Is the pattern temporal, meaning over time; is it across space, or spatial; is it a relationship between two variables; or something else, if so describe).
- Illustrate the pattern through a quick drawing, chart, graph, or even a formula
- Is there a pattern at a different scale (larger or smaller) that helps explain the pattern you found? If so, describe or illustrate (draw something) the pattern
- Does the pattern suggest a cause - effect relationship (one element causes the other element)? Explain.

Here is an example of Patterns from Chapter 6 in NAC.



Stability and Change

Stability and change are ways of describing how a system functions. Whether studying ecosystems or engineered systems, the question is often to determine how the system is changing over time, and which factors are causing the system to become unstable.

PROGRESSION ACROSS THE GRADES	PERFORMANCE EXPECTATION FROM THE NGSS
In grades 9-12, students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems over very short or very long periods of time. They see some changes are irreversible, and negative feedback can stabilize a system, while positive feedback can destabilize it. They recognize systems can be designed for greater or lesser stability.	HS-PS1-6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

The following prompts can help students focus on Stability and Change in the unit of study:

What phenomenon are you studying?

- Sketch a flowchart of the system you are studying. Make sure to include a description of the components, and any connections between them.
- Under what conditions is the system stable?
- Under what conditions does the system change?

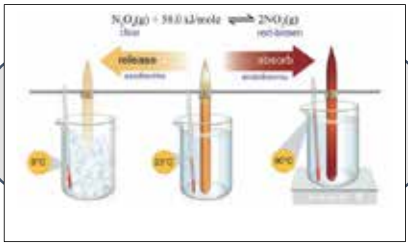
Here is an example of Stability and Change in Chapter 12 of NAC .

Applying **Stability & Change** to the Phenomenon of Designing Chemical Systems

HS-PS1-6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

1) Describe the system & complete the flowchart.

The equilibrium of N_2O_4 (g) < = > NO_2 (g) is driven by auto emissions. Nitrogen tetroxide when heated, can form NO, which is a main component of smog.



3) Under what conditions is the system stable?

The system is stable under conditions involving constant temperatures and concentrations.

Describe Component A

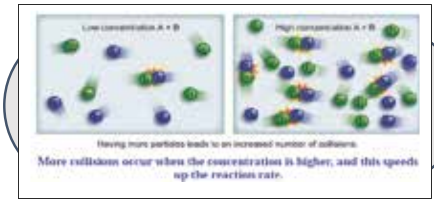
Nitrogen tetroxide (N_2O_4) is formed from the reaction of nitrogen compounds in auto exhaust with oxygen in the air.

Describe Component B

NO_2 is formed from the reaction of N_2O_4 and heat (58kJ/mole).

2) Over what timescale does the system change?

This can change over days, weeks, or months depending on traffic, sunlight and air temperatures.



4) Under what conditions does the system change?

If the temperature increases or the concentration of reactants change, this will lead to a change in NO_2 product as smog.

Systems and System Models

Systems and system models are used by scientists and engineers to investigate natural and designed systems. The purpose of an investigation might be to explore how the system functions, or what may be going wrong. Sometimes investigations are too dangerous or expensive to try out without first experimenting with a model. What phenomenon are you studying? (from NGSS, Appendix G, p. 12)

PROGRESSION ACROSS THE GRADES	PERFORMANCE EXPECTATION FROM THE NGSS
In grades 9-12, students can investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They can use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. They can also use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models. They can also design systems to do specific tasks.	HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

The following prompts can help students focus on Systems and System Models in the unit of study:

- Describe the system
- List the components of the system
- Illustrate the system (draw or sketch) and make sure to include any interactions among components of the system
- Describe the boundary of the system and any inputs and outputs of matter and energy

Here is an example of Systems and System Models in NAC Chapter 19.

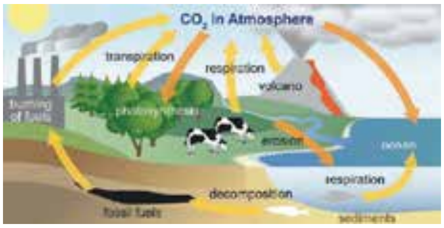
Applying **Systems & Models** to the Phenomenon of Carbon Cycling

HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

1) Describe the system.

The diagram at right shows the major components involved in carbon cycling in the Earth system, including the major reservoirs of the biosphere, atmosphere, geosphere, and hydrosphere. Carbon does change form is it moves, from CO2 to glucose (C6H12O6), to bicarbonate ion (HCO3-). While the geosphere contains the most carbon as rocks and sediments, the oceans and atmosphere contain the most actively moving carbon.

Model the System



3) Illustrate the system in the space provided, and include any relevant interactions among the components of the system.

See the example at left.

2) List the components of the system.

The components include the Sun; the biosphere (animals and plants), the geosphere (crustal rocks and sediments, including fossil fuels), atmosphere, and hydrosphere (oceans and freshwaters). Historically, the flow of carbon from one reservoir to another have been balanced but since the Industrial Revolution, this flow has been altered by human influences. Atmospheric CO2 and ocean bicarbonates (HCO3-) are the chief forms of carbon actively moving around in the Earth System.

4) Describe the boundary of the system and any inputs and outputs of matter and energy.

The boundaries are from the upper atmosphere to the crustal plates. Energy from the sun reaches Earth's surface and while some is reflected back into space (clouds, albedo), much is captured and used by living things. Carbon is captured and stored in ocean waters which cycle over thousands of years, and in sediments and rocks in the movement of crustal plates. Matter is conserved; energy flows into and out of the Earth system.

References

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Graphic Organizer Tools to Support the Crosscutting Concepts, Secondary, by J Peacock and A Peacock, Northeast Georgia Resource and Clarke County Public Schools, available online at https://www.nsta.org/blog/using-crosscutting-concepts-scaffold-student-thinking.

Learning Progressions in A Natural Approach to Chemistry

A Natural Approach to Chemistry is a spiral program. Support for HS-PS1 and HS-PS3 is not confined to single locations in the course; rather, this support is distributed over time. This is done to support the idea that learning is a developmental progression (NGSS, Appendix E). The cognitive demand for the elements of the PEs increases over the course. For example, PS1 and PS2 are introduced in chapter 2, where the periodic table of the elements is first introduced and properties of metals are contrasted with nonmetals. Later, in chapters 6 and 7, the patterns in properties of the groups of elements, such as electronegativity, ion size, likely properties based on valence electrons, etc., is investigated more thoroughly. Chapter 3 introduces basic concepts associated with heat and thermodynamics (HS-PS3, Energy) which are picked up later in chapters 9, 10, 15, and 19.

This allows for a focus on a limited number of core ideas that can be investigated in greater depth throughout the course and provides opportunities to develop SEPs with the DCIs; the NGSS calls this "...intertwin(ing) in designing learning experiences in K-12 science education" (Framework, p. 1-3).

You will find support for the DCI and CCC statements most often in the Student Book and support for the SEP most often in the Lab Investigations Manual (LIM) although you will often find support for each of the three elements in both locations. Locations marked in bold represent formal assessment checkpoints. The following table shows the broad distribution of PEs over the course.

Support for High School Performance Expectations in A Natural Approach to Chemistry

PE WORKING TOWARDS...	STUDENT BOOK	LAB MANUAL
PS1-1	2.1, 5.1, 6.1, 6.2, 7.1, 7.2, 7.3	6B, 6C, 7A
PS1-2	4.1, 6.1, 6.2, 7.2, **7.3**	4C, 7A
PS1-3	2.2, 8.1, 8.2, **8.3**, 9.1	3B
PS1-4	1.4, 12.1, **12.3**	4C, 10C
PS1-5	**12.2**	12A, 12B, 12C
PS1-6	12.2, **12.4**, 12.3	12C, 12A, 12B
PS1-7	4.2, 10.1, 10.2, 10.3, 11.1, 11.2, **11.3**, 11.4, 12.2	4A, 10A
PS1-8	20.1, 20.2, **20.3**, 20.4	20B
PS3-1	3.2, **10.4**	3A, 3B, 9C, 1-C
PS3-2	1.3, 3.1, **9.3**	3A, 3B, 3D, 4A, 9C, 10C, 15A, 15B
PS3-3	9.3, 15.1, **15.4**	15B, 15A, 15C
PS3-4	3.2, 3.3, **3.4**, 19.1	3A, 3B
ETS1-1 to ETS 1-4	Chemical Connections section in most chapters	New LIM project investigations