Chemistry in the Earth System: Integrating Chemistry and Earth and Space Science

Introduction

This course explains how chemical processes help drive the Earth **system [CCC-4]**. Earth and space scientists require a strong background in the fundamentals of **matter [CCC-5]** and chemistry in order to interpret processes that shape the Earth system. A raindrop falls through the air, interacting with the CO_2 and becoming slightly acidic. Water that would have simply flowed through rock, if neutral, now reacts with the minerals in the rock and turns them into clay that will easily erode. Ocean water reacts with volcanic rocks on the ocean bottom so that their physical properties **change [CCC-7]** completely. When these rocks are dragged down into the Earth along plate boundaries, minerals that were once strong enough to withstand great forces now act as lubricants along this great plate boundary fault system. Heat generated deep within the Earth flows outward by conduction and convection, working to equalize the temperature difference between Earth's interior and outer space. This expression of thermodynamics turns an otherwise dead planet into a hotbed of geologic activity plagued by volcanoes and earthquakes. In each case, an Earth or space scientist is studying the chemistry of the situation, perhaps using a computer model to fast forward millions of years of chemical reactions to explain what we see on Earth today. Alongside this scientist is a team of engineers, hoping to use this understanding to design and test solutions to many of society's problems, from natural hazards to global warming or to minimize our impact on the natural world.

Chemistry teachers may not have a strong Earth science background. While it is true that there may be details and historical background that are new, the physical processes are not. Everything in the world is made of matter and chemists study matter. In fact, Earth and space science applications are excellent motivations to the study of physical laws. Earth science can be a door into chemistry.

Even a chemistry teacher that is enthusiastic about this integration in principle may still feel apprehensive about teaching a course that deals with a discipline they may never have studied. Research on self-efficacy shows that a teacher that is not confident will not teach as effectively, often reverting to tasks with low cognitive demand rather than the rich three-dimensional learning expected by California Next Generation Science Standards (CA NGSS). Districts should be mindful and allocate resources to professional learning and collaborative planning time so that teachers can learn from one another. No matter what resources are allocated, teachers will still have to choose how to react to the change.

Purpose and Limitations of this Example Course

The CA NGSS do not specify which phenomena to explore or the order to address topics because phenomena should be relevant to the students in each community and should flow in an authentic manner. This chapter illustrates one possible set of phenomena that will help students achieve the CA NGSS performance expectations. Many of the phenomena selected illustrate California's Environmental Principles and Concepts (EP&Cs), which are an essential part of the CA NGSS (see chapter 1 of this framework). However, the phenomena chosen for this statewide document will not be ideal for every classroom in a state as large and diverse as California. Teachers are therefore encouraged to select phenomena that will engage their students and use this chapter's examples as inspiration for designing their own instructional sequence. For example, the course could be restructured around contemporary issues of health or ecosystem change faced by a local community.

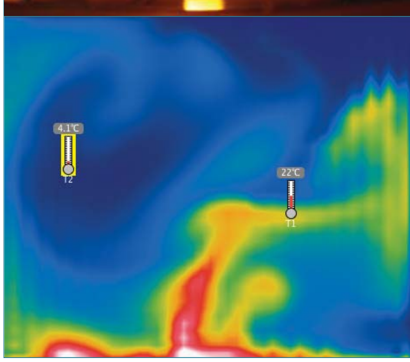
This example course is divided into instructional segments (IS) centered on questions about observations of a specific phenomenon. Different phenomena require different amounts of investigation to explore and understand, so each instructional segment should take a different fraction of the school year. As students achieve the performance expectations within the instructional segment, they uncover **disciplinary core ideas (DCIs)** from physical science, Earth and space science, and engineering. Students engage in multiple practices in each instructional segment, not only those explicitly indicated in the performance expectations. Students also focus on one or two **crosscutting concepts (CCCs)** as tools to make sense of their observations and investigations; the CCCs are recurring themes in all disciplines of science and engineering and help tie these seemingly disparate fields together.

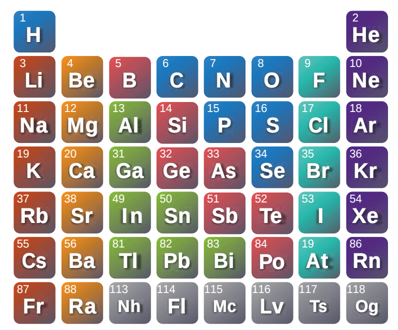
This chapter clarifies the general level of understanding required to meet each performance expectation, but the exact depth of understanding expected of students depends on this course's place in the overall high school sequence. Teachers could modify the content and complexity so that the course serves as a basic freshman introduction to science, serves as a senior capstone that integrates and applies science learning from all previous science courses, or aligns with the expectations of Advanced Placement (AP) or International Baccalaureate (IB) curriculum.

Example Course Mapping for an integrated Chemistry and Earth and Space Science Course

The sequence of this example course (table 7.4) is based on a specific storyline about climate **change [CCC-7]** (figure 7.19). It begins with a tangible example of combustion and food calorimetry, and indeed the combustion of fossil fuels and release of heat, carbon dioxide, and water is a fundamental thread that ties together most of the sections of the course and ensures that chemistry concepts are able to be placed in the context of Earth's systems. While many chemistry courses begin with the study of the atom, this course begins with macroscopic observations of a familiar phenomenon (combustion). The next instructional segment zooms into the microscopic, but begins with simple interactions between particles to explain thermal **energy [CCC-5]** and how it is exchanged within systems. Students then apply their understanding of heat flow to see its role in driving plate tectonics within the Earth system. Only after students are firmly thinking about matter as particles do they zoom in and look at the nature of the particles themselves by studying atoms and how their behaviors are categorized into the periodic table. Students are now equipped to model simple chemical reactions. They return to the combustion chemical reaction and consider the impact that the product of this reaction, carbon dioxide, has on the global climate system. Students consider more advanced chemical reactions and then apply their understanding of chemical equilibrium to a very real problem of ocean acidification, which is also caused by changes in carbon dioxide concentrations in the atmosphere. In the end, students will have explored the fundamentals of chemistry and essential roles that these processes play in Earth's solid geosphere, its liquid hydrosphere, and its gaseous atmosphere.

Table 7.4. Overview of Instructional Segments for High School Three-Course Model Chemistry in the Earth System

	**1 Combustion** In this brief introductory unit, students investigate the amount of stored chemical potential energy in food. They make observations of material properties at the bulk scale that they will later explain at the atomic scale. The themes of combustion and CO_2 tie together several of the instructional segments.
	**2 Heat and Energy in the Earth System** Students develop models of energy conservation within systems and the mechanisms of heat flow. They relate macroscopic heat transport to atomic scale interactions of particles, which they will apply in later units to construct models of interactions between atoms. They use evidence from Earth's surface to infer the heat transport processes at work in the planet's interior.

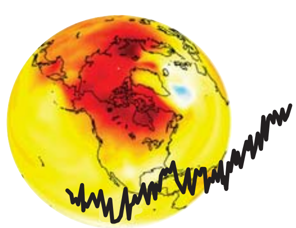


3 Atoms, Elements, and Molecules

Students recognize patterns in the properties and behavior of elements, as illustrated on the periodic table. They use these patterns to develop a model of the interior structure of atoms and to predict how different atoms will interact based on their electron configurations. They use chemical equations to represent these interactions and begin to make simple stoichiometric calculations.

4 Chemical Reactions

Students refine their models of chemical bonds and chemical reactions. They compare the strength of different types of bonds and attractions and develop models of how energy is stored and released in chemical reactions.



5 Chemistry of Climate Change

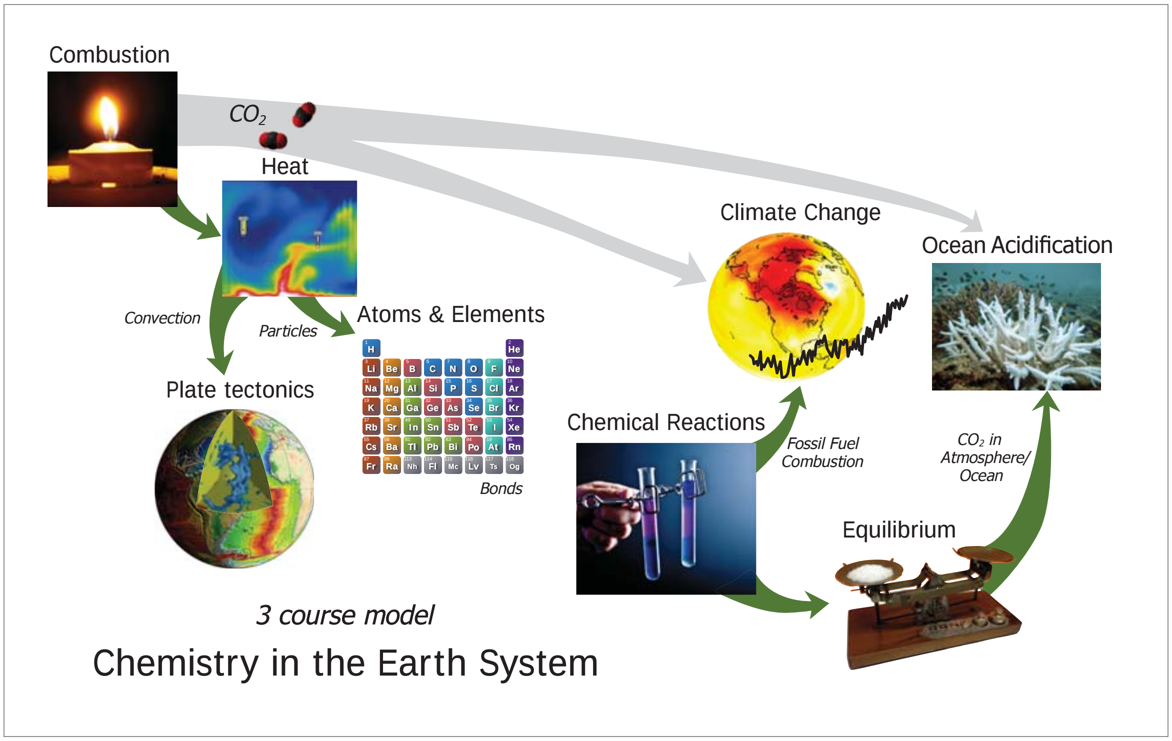
Students develop models of energy flow in Earth's climate. They revisit combustion reactions from IS1 to focus on emissions from fossil fuel energy sources. They apply models of the structures of molecules to explain how different molecules trap heat in the atmosphere. Students evaluate different chemical engineering solutions that can reduce the impacts of climate change.

6 Dynamics of Chemical Reactions and Ocean Acidification

Students investigate the effects of fossil fuel combustion on ocean chemistry. They develop models of equilibrium in chemical reactions and design systems that can shift the equilibrium. Students conduct original research on the interaction between ocean water and shell-building organisms.

Sources: Giardino 2006; M. d'Alessio; M. d'Alessio; Amitchell125 2011; adapted from Geophysical Fluid Dynamics Laboratory 2007; Acropora 2011; A.M. Lebow n.d.

Figure 7.19. Conceptual Flow of Instructional Segments in Example High School Chemistry in the Earth System Course



Sources: Savery 1628; Giardino 2006; M. d'Alessio; adapted from National Oceanic and Atmospheric Administration and National Centers for Environmental Information with Cooperative Institute for Research in Environmental Science 2008; adapted from NASA/Goddard Space Flight Center Scientific Visualization Studio 2002; M. d'Alessio; Amitchell125 2011; adapted from Geophysical Fluid Dynamics Laboratory 2007; Acropora 2011; A.M. Lebow n.d.