Physics of the Universe: Integrating Physics and Earth and Space Sciences

Introduction

Physical processes govern everything in the universe. Geoscientists require a strong background in the laws of physics in order to interpret processes that shape the Earth **system [CCC-4]**, and physicists benefit from applying their **models [SEP-2]** in a range of contexts. Forces of moving water push tiny particles of sand along beds of rivers, sometimes hard enough that they collide with the rocks with such force that a piece of the river bed breaks off. Over time, the Grand Canyon forms. Gravity pulls constantly on rocks at the surface of the Earth, and sometimes the frictional forces resisting movement falter. A landslide crashes down a canyon, destroying everything in its path. The nuclei of atoms thousands of miles below the surface that have remained stable for millions of years spontaneously explode apart, releasing massive amounts of **energy [CCC-5]** and heating up the surrounding rock. A geyser of hot steam erupts in California, releasing some of this excess heat to the surface. In each case, an earth or space scientist is studying the physics of the situation, perhaps using a computer model to fast forward millions of years of **energy [CCC-5]** transfer to **explain [SEP-6]** 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.

Physics teachers may not have a strong Earth science background. While it is true that there may be historical background and details that are new, the physical processes are not. The laws of physics are universal. In fact, Earth and space science applications are excellent motivations to the study of physical laws. A classic example is waves, a topic with such universal importance that the California Next Generation Science Standards (CA NGSS) devotes an entire set of **disciplinary core ideas (DCIs)** in physical science to them. With such significance, it seems unfortunate that the most common classroom application of them is a string held between two people. While it is indeed elegant that such a simple demonstration can capture such a rich process, it is hard to claim that this demonstration is truly exciting or evokes great curiosity. Earthquakes, however, are all about waves and students are filled with questions motivated by personal relevance in California. Earthquakes can be visualized with real-time data downloaded from around the world, or with accelerometers built into nearly every cell phone. Frequency, period, and amplitude are all there on a seismogram, ready to be interpreted. Earth science can be a door into physics.

Even a physics 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 who 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 the CA NGSS. Districts should be mindful and be sure to 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. Science teachers, as a general rule, became science teachers because they love learning about science. Teachers can try to approach this course with an appreciation for the opportunity to learn about a new science alongside students. They can be beacons of curiosity and inquiry in their classrooms. A teacher asking questions and seeking answers is a much better role model than a teacher that appears to know everything.

Purpose and Limitations of this Example Course

The CA NGSS do not specify which phenomena to explore or the order in which to address topics because phenomena need to be relevant to the students who live 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 (PE). 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.

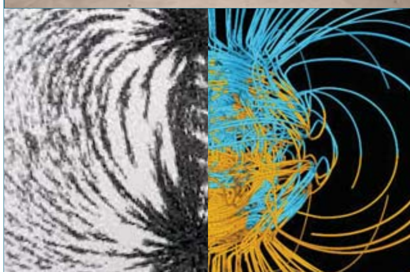
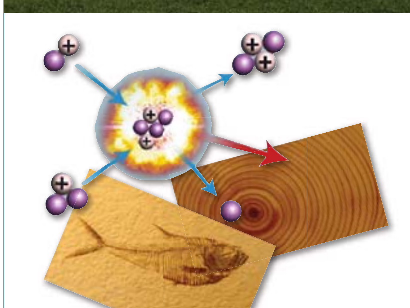
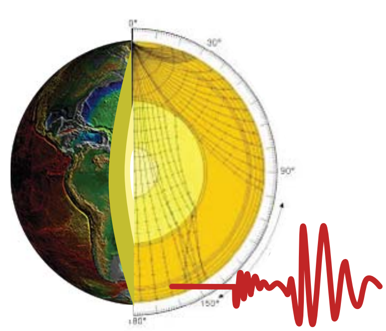
This example course is divided into instructional segments (IS) centered on questions about observations of a specific phenomenon. Different phenomena require different amounts of classroom investigative time to explore and understand, so each instructional segment should take a different fraction of the school year. As students achieve the performance expectations within the instructional segment, they uncover 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 course 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 Physics and Earth and Space Science Course

The sequence of this example course (table 7.6) is based on a specific storyline about renewable **energy [CCC-5]** (figure 7.43). Both physical science and Earth and space science DCIs emphasize how discoveries in those disciplines influence society, but the two differ in which aspects of society they focus upon. Physical science emphasizes society's use of technology while Earth and space science emphasizes humanity's impact on natural **systems [CCC-4]** and the other way around (issues defined in California's EP&Cs). A major emphasis in the first several instructional segments of this course is one topic, relevant to society as a whole, in which these two disciplinary focuses intersect: electricity production. The main engineering design challenges relate to designing, building, evaluating, and refining **systems [CCC-4]** for electricity generation and considering the environmental impacts of each method on the different components of Earth's **systems [CCC-4]**. The theme is not all-encompassing, as many of the performance expectations pertain to core ideas that are disjointed from renewable **energy [CCC-5]**.

Table 7.6. Overview of Instructional Segments for High School Three-Course Model Physics of the Universe

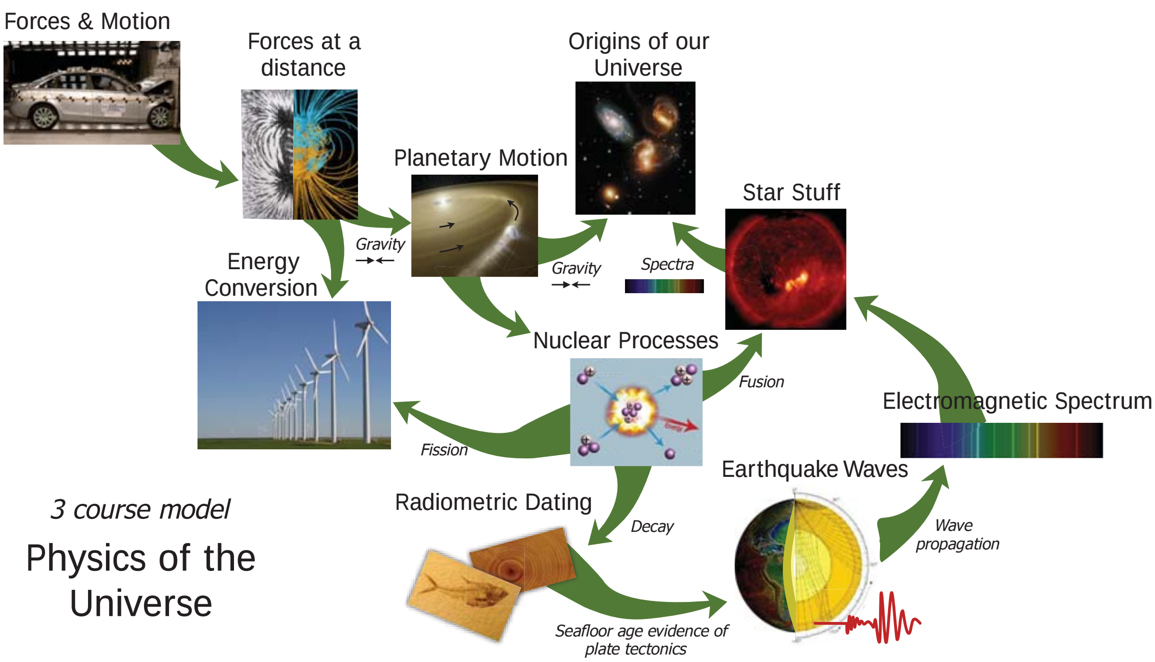
	**1 Forces and Motion** Students make predictions using Newton's laws. Students mathematically describe how changes in motion relate to forces. They investigate collisions in Earth's crust and in an engineering challenge.
	**2 Forces at a Distance** Students investigate gravitational and electromagnetic forces and describe them mathematically. They predict the motion of orbiting objects in the solar system. They link the macroscopic properties of materials to microscopic electromagnetic attractions.
	**3 Energy Conversion** Students track energy transfer and its conversion through different stages of power generation. They evaluate different power plant technologies. They investigate electromagnetism to create models of how generators work and obtain and communicate information about how solar photovoltaic systems operate. They design and test their own energy-conversion devices.
	**4 Nuclear Processes** Students develop a model of the internal structure of atoms and then extend it to include the processes of fission, fusion, and radioactive decay. They apply this model to understanding nuclear power and radiometric dating. They use evidence from rock ages to reconstruct the history of the Earth and processes that shape its surface.
	**5 Waves and Electro-magnetic Radiation** Students make mathematical models of waves and apply them to seismic waves traveling through the Earth. They obtain and communicate information about other interactions between waves and matter with a particular focus on electromagnetic waves. They obtain, evaluate, and communicate information about health hazards associated with electromagnetic waves. They use models of wave behavior to explain information transfer using waves and the wave-particle duality.

6 **Stars and the Origin of the Universe**

Students apply their model of nuclear fusion to trace the flow of energy from the Sun's core to Earth. They use evidence from the spectra of stars and galaxies to determine the composition of stars and construct an explanation of the origin of the universe.

Sources: National Highway Traffic Safety Administration 2016; adapted from Black and Davis 1913, 242, fig. 200; adapted from NASA 2003a; Leaflet 2004; adapted from Wikimedia Commons 2011; adapted from Sorenson 2012; adapted from Jordan 2010; adapted from National Oceanic and Atmospheric Administration and National Centers for Environmental Information with Cooperative Institute for Research in Environmental Science 2008; adapted from Ezekowitz 2008; NASA, ESA, and the Hubble SM4 ERO Team/Space Telescope Science Institute 2009

Figure 7.43. Conceptual Flow of Instructional Segments in Example High School Three-Course Model Physics of the Universe



Sources: National Highway Traffic Safety Administration 2016; adapted from Black and Davis 1913, 242, fig. 200; adapted from NASA 2003a; Leaflet 2004; adapted from NASA/JPL-Caltech 2006; NASA, ESA, and the Hubble SM4 ERO Team/Space Telescope Science Institute 2009; Wikimedia Commons 2011; adapted from Sorenson 2012; adapted from Jordan 2010; National Astronomical Observatory of Japan, Institute of Space and Astronautical Science/Japan Aerospace Exploration Agency 2006; adapted from National Oceanic and Atmospheric Administration and National Centers for Environmental Information with Cooperative Institute for Research in Environmental Science 2008; adapted from Ezekowitz 2008; NASA 2015