Accelerated Model Course Pathways

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The *Framework for K-12 Science Education* and the resulting Next Generation Science Standards (NGSS) build a rich foundation for scientific knowledge and conceptual understanding. In keeping with the vision of the *Framework*, the NGSS were designed to provide the foundation on which students, over multiple years of school, actively engage in scientific and engineering practices (SEPs) and apply crosscutting concepts (CCCs) to deepen their understanding of the core ideas within the various disciplines of science and engineering (National Research Council, 2012, pp. 8–9). The multidimensional approach to the types of learning experiences envisioned as a result of the NGSS denotes a significant departure from what was typically expected in science education. Schools, districts, and/or local education agencies, when building course pathways using the NGSS, must recognize the significant demographic shifts and the diversity of the present science education landscape. The NGSS Appendix D — All Standards, All Students discusses in detail how the diverse nature of today's classrooms can be addressed through the NGSS:

> Successful application of science and engineering practices (e.g., constructing explanations, engaging in argument from evidence) and understanding of how crosscutting concepts (e.g., patterns, structure and function) play out across a range of disciplinary core ideas (e.g., structure and properties of matter, earth materials and systems) will demand increased cognitive expectations of all students. Making such connections has typically been expected only of "advanced," "gifted," or "honors" students. The NGSS are intended to provide a foundation for all students, including those who can and should surpass the NGSS performance expectations. (NGSS Appendix D, p. 1)

While the NGSS represent the science *all* students should know, they are not intended to represent *all the science* that students could know. The *Framework* states:

> More generally, this framework should not be interpreted as limiting advanced courses that go beyond the material included here—all students at the high school level should have opportunities for advanced study in areas of interest to them, and it is hoped that, for many, this will include further study of specific science disciplines in honors or AP courses. Such course options may include topics, such as neurobiology, and even disciplines, such as economics, that are not included in this framework. (NRC, 2012, p. 13)

In keeping with the tenets of the *Framework*, the NGSS Appendix K — Model Course Mapping in Middle and High School describes several model course maps that would provide all students with opportunities to pursue advanced-level science courses, including Advanced Placement (AP) courses.[1] However, to provide opportunities for a discrete, high-achieving stratum of the student population who wish to pursue multiple advanced-level science courses earlier in high school, a more rapid-paced, accelerated pathway of courses may be desirable.

[1] For the purposes of this narrative, we classify advanced science courses as those courses that go beyond Biology, Chemistry, and Physics and often require a prerequisite. Examples of advanced science courses are sequential courses such as Biology II or Chemistry II, Anatomy and Physiology, and AP science courses.

To help schools and districts design accelerated pathways for this unique population of students, the Accelerated NGSS Model Course Maps (ANMCM) were developed. The ANMCM are resources that organize the NGSS in a compressed time frame and could be used by schools and districts to design NGSS-aligned pathways through which high-achieving students would be provided the coursework necessary to access advanced-level science courses in all areas of student interest in early high school. In addition to the ANMCM, resources were created to show the relationship between the NGSS and AP science courses. These resources could be used to show the conceptual similarities between the two sets of courses to provide guidance in the development of the accelerated and advanced courses.

To be clear, given the depth of understanding required by the NGSS, the accelerated pathways should not be considered the status quo or an opportunity to compact or omit key instructional concepts. Rather, the need for the accelerated pathways reflects the reality that some students need or want additional opportunities for advanced-level coursework in science. For the purpose of clarity, the accelerated pathways would serve those students who may be identified as gifted and talented. Gifted, as defined by the National Association for Gifted Children, is described as follows:

> Gifted individuals are those who demonstrate outstanding levels of aptitude (defined as an exceptional ability to reason and learn) or competence (documented performance or achievement in top 10% or rarer) in one or more domains. Domains include any structured area of activity with its own symbol system (e.g., mathematics, music, language) and/or set of sensorimotor skills (e.g., painting, dance, sports).[1]

Overview

As schools, districts, and/or local education agencies start developing accelerated pathways and evaluate how the models and considerations presented here fit into their local contexts, it is expected that a wider variety of accelerated pathways will be collaboratively developed and shared. Depending on the context, the pathways could consist of several different components.

Three proposed ANMCM are included in this document as examples for schools, districts, and/or local education agencies to use when thinking about organization of the PEs for accelerated students. There are two types of maps highlighted in this document. Each type of map is an acceleration of the NGSS so that a student would meet all of the NGSS PEs prior to entering any advanced-level science course, the grade levels that are affected differ. The first type of map involves both middle school and high school courses and is represented in the Five- and Four-Year Models. The second type of map only involves high school courses and is represented in the High School Schedule Model.

[1] "Definitions of Giftedness." *National Association for Gifted Children*. http://www.nagc.org/resources-publications/resources/definitions-giftedness 22 Sept. 2015.

Given the number of shared concepts between the NGSS and AP science courses, three comparison charts that identify the shared concepts are also included to allow for the option of reducing instructional redundancy when developing accelerated pathways.

Accelerated NGSS Model Course Maps

1. **Five-Year Model** **(Grades 6–10)** — The middle school and high school PEs are organized and condensed into a Five-Year Model in which student understanding of concepts is built progressively throughout the course sequence.
2. **Four-Year Model** **(Grades 6–9)** — The middle school and high school PEs are organized and condensed into a Four-Year Model in which student understanding of concepts is built progressively throughout the course sequence.
3. **High School Schedule Model** **(Grades 9–10) —** This model starts in high school and discusses how students can complete the high school PEs through multiple scheduling options.

Considerations for AP Science Courses

Comparison Charts for AP Science Courses — These charts focus specifically on AP courses and similarities between the NGSS and AP science courses to reduce conceptual redundancy. They serve as a guide for how shared conceptual ideas are addressed between the NGSS and AP.

The options presented in this document do not preclude other organizational sequences.

Assumptions for Accelerated NGSS Model Course Maps

To use the proposed ANMCM effectively, it is essential to understand the assumptions that were involved in their creation. This section outlines these assumptions and attempts to clarify the intent and use of the model course maps in further detail below.

1. ANMCM are starting points, not finished products.
2. The design of the ANMCM was built on the model course sequences found in the NGSS Appendix K.
3. The acceleration process can begin in middle school.
4. "All standards, All students"
5. ANMCM are not curricula.
6. Engineering for all.
7. ANMCM ≠ advanced-level science coursework.

1. ANMCM are starting points, not finished products.

Every attempt has been made to describe the intent and assumptions underlying the ANMCM and the process of model development so that states and districts can use similar processes to organize and create their own accelerated course pathway(s). The intent of the ANMCM is not for states, districts, and/or local education agencies to adopt these models as presented. Rather, they are encouraged to use them as a springboard for conversations focused on developing their own course descriptions and sequences. States, districts, and/or local education agencies could use the ANMCM to create pathways of utility customized to their needs and the needs of students, as there may be many different possible configurations of course offerings and sequences, depending on factors such as district size, certifications held, and local graduation requirements. Additionally, in designing their own course sequence models, states, districts, and/or local education agencies should collaborate with various members of the educational community, such as curriculum specialists, gifted and talented specialists, middle and high school educators (including advanced and AP science educators), mathematics educators, and administrators.

The fact that the information in this document is intended as a starting point for districts is further emphasized by the possible uses of the supplemental NGSS/AP correlation documents in customizing course pathways.

2. The design of the ANMCM was built on the model course sequences found in the NGSS Appendix K.

Much work has already been done to organize the NGSS into logical course progressions.

As outlined in the *Framework* and the NGSS Appendix K, the word "model" is used here to represent a tool for understanding, not an ideal state. As stated previously, this distinction is important because the various potential configurations of course offerings and sequences depend heavily on factors such as district size, certifications held, and local graduation requirements. The ANMCM illustrate possible approaches to organizing the content of the NGSS into coherent and rigorous courses that provide accelerated pathways that allow students to experience the full breadth of the NGSS in preparation for earlier involvement in advanced science coursework.

The related model course sequences outlined in the NGSS Appendix K were constructed based on the domain structure of the *Framework* and are the source of the foundational course map structure for this document. More specifically, Model Course Map 1 (the Conceptual Progressions Model) was selected from the NGSS Appendix K as the basis for the ANMCM presented herein. This Conceptual Progressions Model is based on research showing that disciplinary core ideas (DCIs) contain content that can be logically sequenced and arranged so that, for each course, the NGSS performance expectations (PEs) build on the skills and knowledge covered in preceding courses. The Conceptual Progressions Model was best suited as a baseline for the ANMCM because it allows for an effective and efficient integration of DCIs by connecting many concepts and ideas, providing students the opportunity to develop a big-picture understanding within a condensed time frame. Choosing instead to segregate the ANMCM into the different domains of science (e.g., life sciences vs. physical sciences) could result in two significant and potentially negative effects: (1) loss of coherence of the carefully designed progression or "story," and (2) the partitioning of high school PEs in middle school courses based on their scientific discipline rather than on their level of cognitive demand, relationships to other science disciplines, and reliance on prior learning designed into the standards' grade-level progressions. The second effect could be especially problematic as it would add a level of challenge to what is already a significant increase in rigor over the models described in the NGSS Appendix K, requiring students to engage in even more supplemental learning to understand concepts when they are inserted into the learning sequence before their foundational ideas are introduced.

As stated in the NGSS Appendix K, the model course maps expect that every course in the sequence will use instruction to blend all SEPs and CCCs and not just the ones that are outlined in the PEs. The goal is not to teach the PEs but rather to prepare students to demonstrate their proficiency on the PEs by the end of the grade band or course. Even though a particular PE may be placed "in a course," addressing the depth of the PE in its entirety within that course might not be possible. Students may, for example, need repeated exposure to a particular DCI, SEP, or CCC over several courses before they can achieve the proficiency expected in a particular PE by the end of the grade band or course.

Additional information on how the Conceptual Progressions Model was modified for each ANMCM is detailed in the next section. For a complete explanation of the process and logic models used to create Model Course Map 1 (Conceptual Progressions Model) see the NGSS Appendix K.

3. The acceleration process can begin in middle school.

The models presented herein are based in part upon the assumption that meaningful acceleration using the NGSS, for some students, can begin prior to the traditional start of high school in 9th grade. Infusing high school PEs into middle school courses in a way that maintains a coherent progression or story allows acceleration to enhance, rather than detract from, the rich learning experiences students need to prepare them for rigorous, advanced science coursework. The intent of the ANMCM should be to open the door to an increased number of advanced-level science courses for students who have demonstrated the high aptitude and interest to participate in advanced science coursework. Including the middle grades in the acceleration process furthers this goal by allowing for a logical coherence in the arrangement of PEs within the course sequence rather than "chunking" them together into one or two unwieldy high school courses.

More important, the proposed ANMCMs are explicitly intended for students who possess the demonstrated performance and desire for advanced science coursework and/or for whom the courses are developmentally appropriate. The ANMCMs are not intended to provide a "shortcut" for condensing NGSS instruction into one or two years of high school for students who are not preparing to enter advanced coursework. The level of rigor inherent in the NGSS is substantial, and the instructional compression these pathways require increases the cognitive demand even more. An equally important consideration for schools and districts is that most students wishing to pursue the ANMCM will likely need concurrent acceleration in mathematics to support the increased mathematical rigor required for the high school PEs.

It should be recognized that not all schools have the ability to accelerate students beginning in the middle grades. For these schools and students not identified as gifted, an alternative high school "co-acceleration" model is presented.

4. "All Standards, All Students"

The statement "all standards, all students" represents a foundational commitment of the *Framework* and the NGSS; this commitment is referenced in the NGSS Appendix K and discussed at length in Appendix D of the NGSS. While there may be a temptation to omit standards from the ANMCM, the DCIs contained in every PE are foundational for future advanced-level science courses and are essential knowledge to build upon. The ANMCM presented herein preserve the integrity of the NGSS in its entirety while presenting options for students to go beyond the NGSS with advanced-level science coursework.

5. ANMCM are NOT curricula.

The NGSS PEs are student outcomes, NOT curricula. Although SEPs are integrated with particular DCIs and CCCs within each NGSS PE, these intersections *do not predetermine how the three are linked in the curriculum, units, lessons, or instruction;* they simply clarify the expectations of what students will know and be able to do by the end of the grade, grade band, or course. The additional consideration of how PEs will be addressed within courses is an important step in curriculum development. Thus, school and district leaders continue to bear responsibility for creating coherent instructional programs that help students achieve these standards. Within the process of developing an accelerated program using the ANMCM, schools, districts, and/or local education agencies should bring together educators who understand both the pedagogy and the content requirements to create such a model. As stated earlier, curriculum specialists, gifted and talented specialists, middle and high school educators (including advanced and AP science educators), mathematics educators, and administrators should be included in the process.

6. Engineering for all.

In the NGSS, engineering design standards have been integrated throughout the traditionally taught domains of physical science, life science, and Earth and space science. As is more carefully detailed in the NGSS Appendix I — Engineering Design in the NGSS, the NGSS represent a commitment to integrating engineering design into the structure of science education by incorporating it into instruction across all grade levels, from kindergarten through grade 12. The NGSS also include PEs that focus explicitly on engineering design without a science domain context. Within the grade range affected by the proposed ANMCM, there are four engineering design PEs in the 6–8 grade band and four in the 9–12 grade band. All of the model course maps place the stand-alone engineering PEs within all courses in their respective grade bands, as these PEs can help to organize and drive the instruction of the science PEs within each course.

7. ANMCM ≠ advanced-level science coursework.

It is important to understand the distinction between the ANMCM and advanced-level science courses as the terms are used in this document.

"ANMCM" refer to a course model wherein the science standards intended for all students are configured into a time-compressed curriculum sequence to more rapidly prepare high-performing students for opportunities to take numerous advanced-level science courses.

"Advanced-level science courses" refer to more narrowly focused courses that go beyond first-year high school science courses (e.g., Biology, Chemistry, and Physics) and often require a prerequisite. Examples of advanced science courses are sequential courses such as Biology II or Chemistry II, Anatomy and Physiology, and AP science courses. These courses would provide a solid base for students with an interest in the sciences or who intend to pursue science, technology, engineering, and mathematics (STEM) coursework in college.

The models presented in this document represent possible approaches to accelerating the learning of the NGSS, but they do not include any additional PEs. The ANMCM contain no advanced content beyond the significant rigor already embodied in the NGSS; rather, they provide pathways to facilitate delivery of advanced content in additional courses beyond the scope of the NGSS sooner in students' progression through middle and high school. Put differently, students enrolled in an accelerated course pathway learn the full breadth of the NGSS *faster* than their non-accelerated counterparts, including those students enrolled in honors courses, but enrollment in the accelerated pathway alone does not suggest that these students will learn *more*. The value of the accelerated pathways lies in the "found time," or providing accelerated students with opportunities to take additional science courses.

Course Map 1 — Five-Year Model (Grades 6–10)

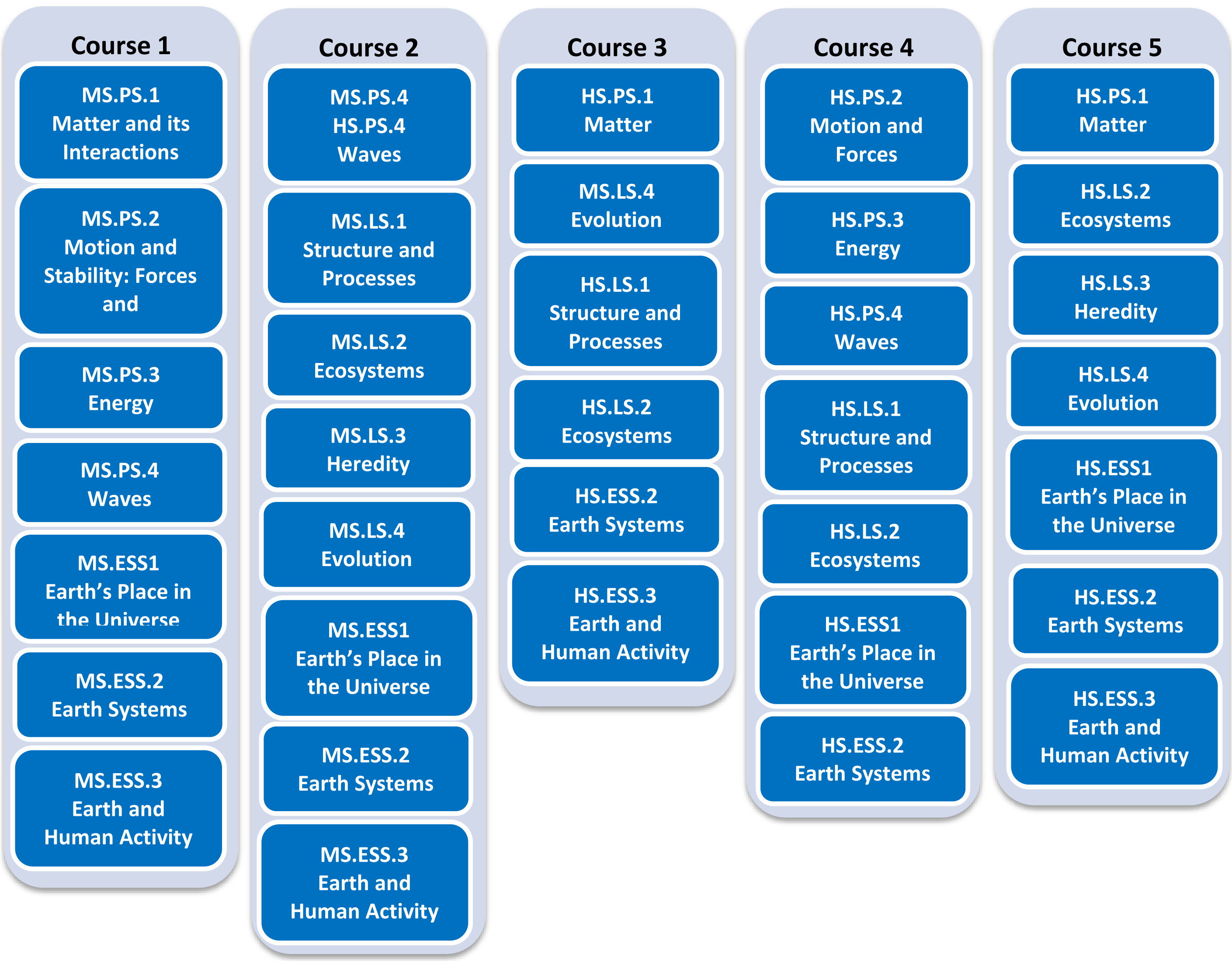
Process and Assumptions: How Was This Course Map Developed?

Using the middle school (MS) and high school (HS) conceptual models from the NGSS Appendix K as the baseline, all of the MS and HS PEs were condensed into five courses intended for grades 6–10. Instead of focusing on the component ideas as the basis for the arrangement, as was done in the NGSS Appendix K Conceptual Progressions Model (see p. 3 of the NGSS Appendix K), this model organized the PEs by DCIs, with each core idea repeating in different grade levels as necessary. To create a logical progression in this map, special attention was paid to highly related concepts. For example, the concept of "Earth's Place in the Universe" (MS and HS ESS1 PEs) was paired with the "Evolution of Life on Earth" (MS and HS LS4 PEs), as they are both part of a broader narrative revealing how Earth and all living things have changed over time. Additionally, instances where one concept informs another were also identified and placed in a conceptual order. For instance, the concept of heredity are necessary to inform a true understanding of the process of evolution. So while these course progressions do not define an instructional sequence within each course, some important foundational relationships within courses suggest logical sequencing.

In examining the Conceptual Progressions Model at grade 6 in the NGSS Appendix K , it became evident that a large variety of concepts were already in place that were foundational to students' future understanding; thus, the Five-Year Model presented below looks largely the same at grade 6 as the NGSS Appendix K Conceptual Progressions Model. The map of the concepts and how they are organized into courses is shown in Figure 1. By considering the storyline of each PE and the logical progression of the foundational relationships, the Five-Year Model should serve as an effective and efficient model that allows for depth of understanding and connectedness for learners.

Figure 1: Concept Progression for the Five-Year Model Course Map

The figure below outlines the first step of organizing the NGSS into ANMCM for grades 6–10 based on a conceptual progression of the concepts outlined in the DCIs of the *Framework*.



After developing an initial storyline within each course, the next goal was to maintain a balance of PEs among the courses as well as to find a logical balance of content areas included within each course. The complexity of ideas required for learners and the cognitive demand of the PEs were considered in determining what PEs to include in each course. In addition, the mathematics required to be successful with particular PEs and the concurrent progression of mathematical skills, especially in regard to the middle-level courses, were also considered. For example, in Course 2 (7th grade), HS-PS4-1 requires an understanding of basic algebraic concepts to explain the relationships among wave components. The Common Core State Standards include algebraic relationships in the 7th grade standards, but curricula designed to implement the accelerated pathways also need to take into account the curriculum sequence of the mathematics instruction the students receive. This requires scheduling the instructional unit to address HS-PS4-1 after (or perhaps concurrent with) instruction in the required mathematics concepts. Providing students with the necessary mathematics to support the ANMCM is an important consideration for schools, districts, and/or local education agencies that are considering implementing such a model.

Table 1: Five-Year Model Course Map (Grades 6–10)

The table below organizes the middle and high school NGSS PEs into the Five-Year Model in which student understanding of concepts is built progressively throughout the course sequence. In this table, the component ideas are arranged into courses based on the organization shown in Figure 1.

Course 1

Matter and its Interactions	MS-PS1-1.
	MS-PS1-2.
	MS-PS1-3.
	MS-PS1-4.
	MS-PS1-5.
	MS-PS1-6.
Motion and Stability: Forces and Interactions	MS-PS2-1.
	MS-PS2-2.
	MS-PS2-3.
	MS-PS2-4.
	MS-PS2-5.
Energy	MS-PS3-1.
	MS-PS3-2.
	MS-PS3-3.
	MS-PS3-4.
	MS-PS3-5.
Waves	MS-PS4-1.
	MS-PS4-2.
Earth's Place in the Universe	MS-ESS1-1.
	MS-ESS1-2.
	MS-ESS1-3.
Earth Systems	MS-ESS2-2.
	MS-ESS2-3.
	MS-ESS2-4.
	MS-ESS2-5.
	MS-ESS2-6.
Earth and Human Activity	MS-ESS3-1.
Engineering Design	MS-ETS1-1.
	MS-ETS1-2.
	MS-ETS1-3.
	MS-ETS1-4.

Course 2

Waves	HS-PS4-1
	HS-PS4-2
	MS-PS4-3
Structure and Process	MS-LS1-1.
	MS-LS1-2.
	MS-LS1-3.
	MS-LS1-4.
	MS-LS1-5.
	MS-LS1-6.
	MS-LS1-7.
	MS-LS1-8.
Ecosystems	MS-LS2-1.
	MS-LS2-2.
	MS-LS2-3.
	MS-LS2-4.
	MS-LS2-5.
Heredity	MS-LS3-1
	MS-LS3-2
Evolution	MS-LS4-1.
	MS-LS4-2.
	MS-LS4-3.
	MS-LS4-4.
	MS-LS4-5.
	MS-LS4-6.
Earth's Place in the Universe	MS-ESS1-4
Earth Systems	MS-ESS2-1
	MS-ESS2-5
	MS-ESS2-6
Earth and Human Activity	MS-ESS3-1.
	MS-ESS3-2
	MS-ESS3-3.
	MS-ESS3-4
	MS-ESS3-5
Engineering Design	MS-ETS1-1.
	MS-ETS1-2.
	MS-ETS1-3.
	MS-ETS1-4.

Course 3

Matter	HS-PS1-1.
	HS-PS1-2.
	HS-PS1-3.
	HS-PS1-7
	HS-PS1-8
Evolution	MS-LS4-1.
	MS-LS4-2.
	MS-LS4-3.
	MS-LS4-4.
	MS-LS4-5.
	MS-LS4-6.
Structure and Process	HS-LS1-1.
	HS-LS1-2.
	HS-LS1-3.
	HS-LS1-4.
Ecosystems	HS-LS2-1.
	HS-LS2-2.
Earth Systems	HS-ESS2-1.
	HS-ESS2-2.
	HS-ESS2-3.
	HS-ESS2-4.
	HS-ESS2-5
Earth and Human Activity	HS-ESS3-2
Engineering Design	MS-ETS1-1.
	MS-ETS1-2.
	MS-ETS1-3.
	MS-ETS1-4.

Course 4

Motion and Forces	HS-PS2-1.
	HS-PS2-2.
	HS-PS2-3.
	HS-PS2-4.
	HS-PS2-5.
	HS-PS2-6.
Energy	HS-PS3-1.
	HS-PS3-2.
	HS-PS3-3.
	HS-PS3-4.
	HS-PS3-5
Waves	HS-PS4-3
	HS-PS4-4
	HS-PS4-5
Structure and Process	HS-LS1-5
	HS-LS1-6
	HS-LS1-7
Ecosystems	HS-LS2-3
	HS-LS2-4
	HS-LS2-5
Earth's Place in the Universe	HS-ESS1-1
	HS-ESS1-2
	HS-ESS1-3
	HS-ESS1-4
Earth Systems	HS-ESS2-6
Engineering Design	HS-ETS1-1.
	HS-ETS1-2.
	HS-ETS1-3.
	HS-ETS1-4.

Course 5

Matter	HS-PS1-4
	HS-PS1-5
	HS-PS1-6
Ecosystems	HS-LS2-6
	HS-LS2-7
	HS-LS2-8
Heredity	HS-LS3-1
	HS-LS3-2
	HS-LS3-3
Evolution	HS-LS4-1
	HS-LS4-2
	HS-LS4-3
	HS-LS4-4
	HS-LS4-5
	HS-LS4-6
Earth's Place in the Universe	HS-ESS1-5
	HS-ESS1-6
Earth Systems	HS-ESS2-7
Earth and Human Activity	HS-ESS3-1
	HS-ESS3-3
	HS-ESS3-4
	HS-ESS3-5
	HS-ESS3-6
Engineering Design	HS-ETS1-1.
	HS-ETS1-2.
	HS-ETS1-3.
	HS-ETS1-4.

Accommodating Students Entering the Five-Year Model After 6th Grade

One of several important factors to consider when designing curricula, developing placement criteria, or managing scheduling logistics is the likelihood that students will both enter and exit accelerated pathways at different points in their progression through grades 6–10.

In the case of students who seek to exit the model pathway, placing them into a non-accelerated section of the course may be ideal. Conversely, those students leaving the accelerated pathway because the pace is overwhelming may have different needs in their new classes and might briefly need access to some specific interventions to remediate concepts not mastered in the accelerated pathway. Further, in the event that either such student learns key concepts ahead of his or her new classmates, his or her new science teacher may need to provide opportunities for extended or differentiated learning when those duplicated concepts are taught.

Students may not develop an interest in pursuing accelerated STEM coursework until after 6th grade and therefore may seek to enter the pathway late. While some students can catch up with their accelerated counterparts "on the fly," most would benefit from some manner of focused remediation to eliminate the knowledge gap between the non-accelerated instructional program and the Five-Year Model. Schools would need to provide remediation for students in these PEs, through a separate remediation program, summer remediation, or a concurrent remediation model.

The tables below detail the additional accelerated PEs included in each year of the model as compared to the Conceptual Progressions Model for Middle School. These tables are cumulative: Students entering the accelerated pathway at the end of 8th grade would need remediation in the added PEs from both the 7th and 8th grades.

Added PEs for **6th grade** (Course 1) as compared to Table 1: Conceptual Progressions Model Course Map for Middle School, Appendix K (p. 11)		
Physical Science	Life Science	Earth/Space Science
None	None: This model moves two performance expectations — MS-LS2-1 and MS-LS2-2 — to 7th grade.	None

Added PEs for **7th grade** (Course 2) as compared to Table 1: Conceptual Progressions Model Course Map for Middle School, Appendix K (p. 11)		
Physical Science	Life Science	Earth/Space Science
HS-PS4-1 HS-PS4-2	MS-LS1-8 MS-LS2-3 MS-LS2-4 MS-LS2-5 MS-LS3-1 MS-LS3-2 MS-LS4-1 MS-LS4-2 MS-LS4-3 MS-LS4-4 MS-LS4-5 MS-LS4-6	MS-ESS1-4 MS-ESS3-1 MS-ESS3-3 MS-ESS3-4 MS-ESS3-5

Added PEs for **8th grade** (Course 3) as compared to Table 1: Conceptual Progressions Model Course Map for Middle School, Appendix K (p. 11)		
Physical Science	Life Science	Earth/Space Science
HS-PS1-1 HS-PS1-2 HS-PS1-3 HS-PS1-7 HS-PS1-8	HS-LS1-1 HS-LS1-2 HS-LS1-3 HS-LS1-4 HS-LS2-1 HS-LS2-2	HS-ESS2-1 HS-ESS2-2 HS-ESS2-3 HS-ESS2-4 HS-ESS2-5 HS-ESS3-2

Added PEs for **HS 1** (Course 4) as compared to Table 2: Conceptual Progressions Model Course Map for High School, Appendix K (p. 12)		
Physical Science	Life Science	Earth/Space Science
HS-PS3-5 HS-PS4-4	HS-LS1-5 HS-LS1-6 HS-LS1-7 HS-LS2-3 HS-LS2-4 HS-LS2-5	HS-ESS1-1 HS-ESS1-2 HS-ESS1-3 HS-ESS2-6

Added PEs for **HS 2** (Course 5) as compared to Table 2: Conceptual Progressions Model Course Map for High School, Appendix K (p. 12) Note: This listing duplicates the PEs listed for Conceptual Progressions Map Course 3 since students entering the pathway at this point would lack only the content reserved for that course.		
Physical Science	Life Science	Earth/Space Science
HS-PS1-8	HS-LS2-6 HS-LS2-7 HS-LS2-8 HS-LS4-1 HS-LS4-2 HS-LS4-3 HS-LS4-4 HS-LS4-5 HS-LS4-6	HS-ESS1-5 HS-ESS1-6 HS=ESS2-7 HS-ESS3-3 HS-ESS3-4 HS-ESS3-5 HS-ESS3-6

To understand how these tables are intended to be used, consider the scenario of a student who decides to enter an accelerated pathway at the beginning of his or her 8th grade year. The table above indicates that a student in this accelerated pathway will have received instruction in 19 additional PEs (two physical science, 12 life science, five Earth/space science) as compared to students following the "standard" Conceptual Progressions Model for Middle School. Using this table, an accelerated remediation plan could be designed to differentiate instruction and allow this student to receive instruction in the gap standards.

If the same student wished to pursue this accelerated pathway at the end of 8th grade, there would be a need to remediate the 17 "missing" PEs from 8th grade as well as the 19 identified from 7th grade. From these two examples, it becomes clear that the challenges associated with facilitating remediation become more difficult depending on how late students enter into the accelerated pathways.

In some cases, a focused system of interventions will be needed. Some possible strategies might include:

- Before- or after-school individualized tutoring with faculty;
- Mentoring partnerships with higher education, local practitioners, or volunteers;
- Virtual content assistance from online content providers;
- Paired remediation with upper-level high school or college students in multiple courses;
- "Auditing" of portions of other science courses for needed PEs; and
- Independent study or project-based learning outside the school day.

Course Map 2 — Four-Year Model (Grades 6–9)

Process and Assumptions: How Was This Course Map Developed?

To create this Four-Year Model, careful consideration was given to instructional efficiency, and the Five-Year Model, discussed above, was used as a starting point. To condense the Five-Year Model further, the PEs of the middle course (Course 3, grade 8) were redistributed to the other four courses (originally Courses 1, 2, 4, and 5). The reason for this was that the cognitive levels of the first and last courses could not be redistributed because they were the least and most difficult PEs. By redistributing the middle course, the PEs could be shifted to both higher and lower grade levels, leading to thoughtful consideration of the DCIs covered in each course. While an integrated approach was maintained, the overall instructional efficiency became crucial. For example, although in both the Conceptual Progressions Model of the NGSS Appendix K and the Five-Year Model the topics of heredity and evolution are introduced in early courses and covered in more depth in later courses, it was determined that these highly complex and interdisciplinary concepts would be better bundled together in the last course. This bundling allows students the time in other courses to develop understanding of foundational DCIs so that they can apply that understanding to these concepts in the last course. In such a condensed course map, it is critical that students develop a deep understanding of each DCI at each exposure rather than spiraling DCIs and building upon prior exposures. With proper instruction and support, students participating in accelerated model pathways should be able to grasp all components of the PE within a single course; therefore all repeated PEs from the Conceptual Progressions Model were placed in the course in which they were introduced for the Five-Year Model. However, in at least one case, PEs had to be placed in certain grade levels due to a dependence on the simultaneous mathematical development of students. This highly condensed Four-Year Model serves to integrate DCIs with a maximal depth of understanding. The relationships between PEs that address similar concepts were again considered, (see the concept map in Figure 2). The Four-Year Model builds understanding of each DCI from one course to another, allowing for a highly accelerated big-picture understanding of DCIs and CCCs while integrating all SEPs within each course.

To be clear, the Four-Year Model is appropriate for only a very limited number of extremely academically gifted and talented students. The degree of time compression needed to condense this comprehensive set of standards into three middle school courses and one high school course imparts additional challenges beyond those that are inherent in the rigor of the standards. Schools wishing to employ this approach will need to carefully consider the demands on the classroom instructional approaches required, as well as the supports available for maintaining such an intense level of acceleration. Additionally, accommodating students who transition into the pathway after 6th grade will present significant challenges. Schools should consider this pathway only after carefully considering these and other possible implications. Innovative instructional approaches such as "flipped classrooms," mentoring partnerships, fostering relationships with college faculty and/or scientific practitioners, and virtual instructional support may be needed to facilitate the effective implementation of this model. Many schools and their surrounding communities, especially smaller or more rural ones, may not have the access to the supporting resources needed to employ this model.

Figure 2: Concept Progression for the Four-Year Model Course Map

The figure below outlines the first step of organizing the NGSS into accelerated courses for grades 6–9 based on a conceptual progression of the concepts outlined in the DCIs of the *Framework*.

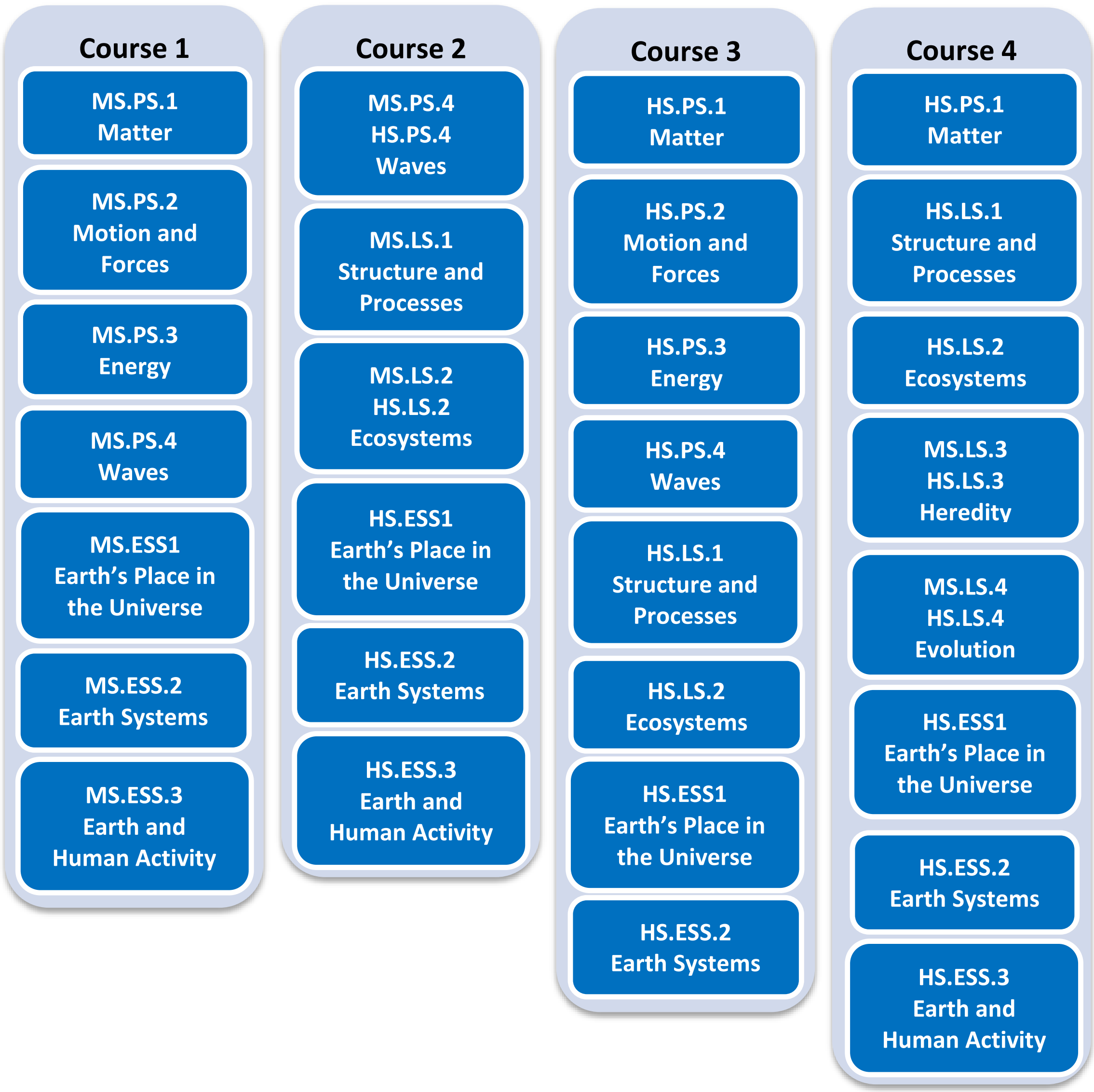


Table 2: Four-Year Model Course Map (Grades 6–9)

The table below organizes the middle and high school NGSS PEs into the Four-Year Model in which student understanding of concepts is built progressively throughout the course sequence. In this table, the component ideas are arranged into courses based on the organization shown in Figure 2.

Course 1

Matter	MS-PS1-1.
	MS-PS1-2.
	MS-PS1-3.
	MS-PS1-4.
	MS-PS1-5.
	MS-PS1-6.
Motion and Forces	MS-PS2-1.
	MS-PS2-2.
	MS-PS2-3.
	MS-PS2-4.
	MS-PS2-5.
Energy	MS-PS3-1.
	MS-PS3-2.
	MS-PS3-3.
	MS-PS3-4.
	MS-PS3-5.
Waves	MS-PS4-1.
	MS-PS4-2.
Earth's Place in the Universe	MS-ESS1-1.
	MS-ESS1-2.
	MS-ESS1-3.
Earth Systems	MS-ESS2-1
	MS-ESS2-2.
	MS-ESS2-3.
	MS-ESS2-4.
	MS-ESS2-5
	MS-ESS2-6
Earth and Human Activity	MS-ESS3-1.
Engineering Design	MS-ETS1-1.
	MS-ETS1-2.
	MS-ETS1-3.
	MS-ETS1-4.

Course 2

Waves	MS-PS4-3
	HS-PS4-1
	HS-PS4-2
Structure and Process	MS-LS1-1.
	MS-LS1-2.
	MS-LS1-3.
	MS-LS1-4.
	MS-LS1-5.
	MS-LS1-6.
	MS-LS1-7.
	MS-LS1-8.
Ecosystems	MS-LS2-1.
	MS-LS2-2.
	MS-LS2-3.
	MS-LS2-4.
	MS-LS2-5.
	HS-LS2-1.
	HS-LS2-2.
Earth's Place in the Universe	MS-ESS1-4
Earth Systems	HS-ESS2-1.
	HS-ESS2-2.
	HS-ESS2-3.
	HS-ESS2-4.
	HS-ESS2-5
Earth and Human Activity	MS-ESS3-2
	MS-ESS3-3.
	MS-ESS3-4
	MS-ESS3-5
	HS-ESS3-2
Engineering Design	MS-ETS1-1.
	MS-ETS1-2.
	MS-ETS1-3.
	MS-ETS1-4.

Course 3

Matter	HS-PS1-1.
	HS-PS1-2.
	HS-PS1-3.
	HS-PS1-7
	HS-PS1-8
Motion and Forces	HS-PS2-1.
	HS-PS2-2.
	HS-PS2-3.
	HS-PS2-4.
	HS-PS2-5.
	HS-PS2-6.
Energy	HS-PS3-1.
	HS-PS3-2.
	HS-PS3-3.
	HS-PS3-4.
	HS-PS3-5
Waves	HS-PS4-3
	HS-PS4-4
	HS-PS4-5
Structure and Processes	HS-LS1-5
	HS-LS1-6
	HS-LS1-7
Eosystems	HS-LS2-3
	HS-LS2-4
	HS-LS2-5
Earth's Place in the Universe	HS-ESS1-1
	HS-ESS1-2
	HS-ESS1-3
	HS-ESS1-4
Earth Systems	HS-ESS2-6
Engineering Design	MS-ETS1-1.
	MS-ETS1-2.
	MS-ETS1-3.
	MS-ETS1-4.

Course 4

Matter	HS-PS1-4
	HS-PS1-5
	HS-PS1-6
Stucture and Process	HS-LS1-1.
	HS-LS1-2.
	HS-LS1-3.
	HS-LS1-4.
Ecosystems	HS-LS2-6
	HS-LS2-7
	HS-LS2-8
Heredity	MS-LS3-1
	MS-LS3-2
	HS-LS3-1
	HS-LS3-2
	HS-LS3-3
Evolution	MS-LS4-1.
	MS-LS4-2.
	MS-LS4-3.
	MS-LS4-4.
	MS-LS4-5.
	MS-LS4-6.
	HS-LS4-1
	HS-LS4-2
	HS-LS4-3
	HS-LS4-4
	HS-LS4-5
	HS-LS4-6
Earth's Place in the Universe	HS-ESS1-5
	HS-ESS1-6
Earth Systems	HS-ESS2-7
Earth and Human Activity	HS-ESS3-1
	HS-ESS3-3
	HS-ESS3-4
	HS-ESS3-5
	HS-ESS3-6
Engineering Design	HS-ETS1-1.
	HS-ETS1-2.
	HS-ETS1-3.
	HS-ETS1-4.

Accommodating Students Entering the Four-Year Model After 6th Grade

As with the Five-Year Model, students may not develop an interest in pursuing accelerated STEM coursework until after 6th grade and may therefore seek to enter this accelerated pathway at a point other than the beginning. Given the extremely demanding level of acceleration inherent in this model, some sort of focused remediation is essential for even the most academically gifted and talented students to have a reasonable expectation of successfully entering this course progression midway through. For this reason, as well as the ones discussed earlier, schools and districts should carefully weigh the level of support they can provide to students before offering this dramatically accelerated course sequence. The same instructional suggestions listed with the Five-Year Model could also be applied to this one, but with an even greater degree of intensity.

The tables below detail the additional accelerated PEs included in each year of the model as compared to the Conceptual Progressions Model for Middle School. These tables are cumulative: Students entering the accelerated pathway at the end of 8th grade would need remediation in the added PEs from both the 7th and 8th grades.

Added PEs for **6th grade** (Course 1) as compared to Table 1: Conceptual Progressions Model Course Map for Middle School, Appendix K (p. 11)		
Physical Science	Life Science	Earth/Space Science
None	None: This model moves two performance expectations — MS-LS2-1 and MS-LS2-2 — to 7th grade.	None

Added PEs for **7th grade** (Course 2) as compared to Table 1: Conceptual Progressions Model Course Map for Middle School, Appendix K (p. 11)		
Physical Science	Life Science	Earth/Space Science
HS-PS4-1 HS-PS4-2	MS-LS1-8 MS-LS2-3 MS-LS2-4 MS-LS2-5 HS-LS2-1 HS-LS2-2	MS-ESS1-4 HS-ESS2-1 HS-ESS2-2 HS-ESS2-3 HS-ESS2-4 HS-ESS2-5 MS-ESS3-3 MS-ESS3-4 MS-ESS3-5 HS-ESS3-2

Added PEs for **8th grade** (Course 3) as compared to Table 1: Conceptual Progressions Model Course Map for Middle School, Appendix K (p. 11)		
Physical Science	Life Science	Earth/Space Science
HS-PS1-1 HS-PS1-2 HS-PS1-3 HS-PS1-7 HS-PS1-8 HS-PS2-1 HS-PS2-2 HS-PS2-3	HS-LS1-5 HS-LS1-6 HS-LS1-7 HS-LS2-3 HS-LS2-4 HS-LS2-5	HS-ESS1-1 HS-ESS1-2 HS-ESS1-3 HS-ESS1-4 HS-ESS2-6

HS-PS2-4		
HS-PS2-5		
HS-PS2-6		
HS-PS3-1		
HS-PS3-2		
HS-PS3-3		
HS-PS3-4		
HS-PS3-5		
HS-PS4-3		
HS-PS4-4		
HS-PS4-5		

Added PEs for **HS 1** (Course 4) as compared to Table 2: Conceptual Progressions Model Course Map for High School, Appendix K (p. 12) Note: This listing duplicates the PEs listed for Conceptual Progressions Map Courses 2 and 3 since students entering the pathway at this point would lack only the content reserved for Course 4.*		
Physical Science	Life Science	Earth/Space Science
HS-PS3-5	HS-LS1-1	HS-ESS1-1
HS-PS4-4	HS-LS1-2	HS-ESS1-2
HS-PS1-8	HS-LS1-3	HS-ESS1-3
	HS-LS1-4	HS-ESS2-1
	HS-LS1-5	HS-ESS2-2
	HS-LS1-6	HS-ESS2-3
	HS-LS1-7	HS-ESS2-4
	HS-LS2-3	HS-ESS2-6
	HS-LS2-4	HS-ESS3-1
	HS-LS2-5	HS-ESS1-5
	HS-LS3-1	HS-ESS1-6
	HS-LS3-2	HS=ESS2-7
	HS-LS3-3	HS-ESS3-3
	HS-LS2-6	HS-ESS3-4
	HS-LS2-7	HS-ESS3-5
	HS-LS2-8	HS-ESS3-6
	HS-LS4-1	
	HS-LS4-2	
	HS-LS4-3	
	HS-LS4-4	
	HS-LS4-5	
	HS-LS4-6	

*To present a coherent conceptual story, the Four-Year Model moves a number of middle school PEs into the fourth course, which is presumed to be the first (and only) foundational high school course in this pathway. Since students entering the pathway at the beginning of high school are presumed to have experienced the entire set of middle school PEs, those PEs are not listed in this table.

Course Map 3 — High School Schedule Model (Grades 9–10)

Process and Assumptions: How Was This Course Map Developed?

There may be some circumstances in which involving feeder middle schools in the meaningful acceleration of science curriculum is either impossible or impractical. In those cases, the opportunity still potentially exists to move students into AP courses at or even before the beginning of their third year of high school through the use of condensed scheduling. Students may learn the concepts of the NGSS by taking courses adhering to any of the unmodified Appendix K models. “Acceleration,” in this case, would be the result of either concurrent or rapid sequential scheduling rather than the shifting and compacting PEs into a smaller number of courses. This approach could be employed in either of two ways:

1. Accelerated course sequence through block or trimester scheduling

Flexible schedule structures such as block or trimester scheduling provide additional opportunities compared to the traditional year-long course structure. The three (or four) required foundational NGSS science courses could potentially be scheduled in sequence and still allow students to have completed the full span of the NGSS by the middle or end (in the case of the Four-Year Model) of the second year. For example, in the Conceptual Progressions Model, a student could take Course 1 as a first-year, first-semester class; take Course 2 in the second semester of the first year; and complete the sequence with Course 3 in the middle of the second year. Other variations could obviously be employed, such as scheduling Course 1 as a full-year class and then Courses 2 and 3 as half-year blocks during the second year. The permutations of this approach are limited only by the availability of certified staff, classroom space, and flexibility within the scheduling framework.

2. Accelerated sequence through concurrent scheduling

In this approach, students would be enrolled in two courses concurrently. This approach would likely be more cognitively demanding than the sequential approach above. Careful consideration would need to be given to which courses are offered concurrently, and student understanding would benefit greatly if teachers communicate and coordinate, achieving maximum efficiency and instructional impact.

Because the sequence of the Conceptual Progressions Model was intentionally designed to scaffold student learning by arranging foundational concepts to be taught first, it is recommended that concurrent scheduling not occur with Course 1. Rather, Course 2 and Course 3 could be scheduled together as second-year courses. This would allow students to have received instruction in the entire NGSS by the end of grade 10 and allow them to schedule two full years of AP courses.

Since the other course models from the NGSS Appendix K (Science Domains, Modified Science Domains, and Modified Science Domains — Four Courses) do not imply a sequence or progression, any two courses could potentially be scheduled concurrently. Such scheduling decisions could be made based on logistical considerations and instructional factors such as staff certifications and availability, student numbers, and the personal preferences of both teachers and students.

Careful instructional planning would enhance courses offered concurrently by making logical connections between/across their curricula. At its most basic, this approach would entail intentionally scheduling all concurrent acceleration students into the same two sections of the courses so teachers could communicate and plan in a way that supports all such students. The teachers could then construct curriculum maps that intentionally pair related concepts across the two courses to maximize cognitive effort by allowing students to focus deeply on related concepts in both courses rather than dividing their focus between two less similar ideas. In the case of a student taking Courses 2 and 3 of the Conceptual Progressions Model concurrently, communication between instructors would likely mean that ESS1.A (The Universe and its Stars) was taught in Course 2 at the same time as PS1.C (Nuclear Processes) in Course 3 since nuclear processes are the reason stars release energy. Another example would be learning ESS2.A (Earth Materials and Systems) in Course 2 along with ESS3.C (Human Impacts on Earth Systems) in Course 3.

The efficiency of this model can be maximized by intentional planning across/between concurrent courses to maintain some sense of a coherent story when transitioning from one class to the other. Some connections are obvious, such as when concepts share the same DCI element, as in the ESS examples below. Others may require a careful reading of the *Framework* to establish logical and coherent connections. As with most models, there is no single "right" way to organize concurrent courses, and instructional plans may be influenced based on factors outside of the standards themselves.

In the first table (Chemistry and Physics), an obvious connection is the suggestion that the ESS2 DCI elements be taught concurrently. The pairing of PS1.C (Nuclear Processes) with ESS2.B (Plate Tectonics) is not as immediately apparent and is an example of a connection being made based on a strong conceptual relationship. The radioactive decay of isotopes inside the Earth produces the heat driving the convection currents responsible for tectonic activity, making the teaching of the two ideas concurrently a logical instructional decision.

The example below offers suggestions for concurrent teaching of concepts at the DCI element level. It is based upon the Modified Science Domains Model from the NGSS Appendix K.

Possible DCIs to be taught concurrently	
Chemistry	Physics
PS1.C: Nuclear Processes	ESS2.B: Plate Tectonics & Large-Scale System Interactions
PS3.B: Conservation of Energy & Energy Transfer PS3.D: Energy in Chemical Processes & Everyday Life	PS3.A: Definitions of Energy PS3.C: Relationship Between Energy & Forces
ESS2.C: Role of Water in Earth's Surface Processes ESS2.D: Weather & Climate	ESS2.A: Earth Materials & Systems

Possible DCIs to be taught concurrently	
Biology	Chemistry
LS1.C: Organization for Matter & Energy Flow in Ecosystems	PS1.B: Chemical Reactions
LS2.B: Cycles of Matter & Energy Transfer in Ecosystems	PS3.B: Conservation of Energy & Energy Transfer PS3.D: Energy in Chemical Processes & Everyday Life
ESS2.E: Biogeology	ESS2.C: The Roles of Water in Earth Surface Processes ESS2.D: Weather & Climate
ESS3.B: Natural Hazards ESS3.C: Human Impacts on Earth Systems	ESS3.D: Global Climate Change

Possible DCIs to be taught concurrently	
Biology	Physics
LS1.C: Organization for Matter & Energy Flow in Ecosystems LS2.B: Cycles of Matter & Energy Transfer in Ecosystems	PS3.A: Definitions of Energy
LS1.D: Information Processing	PS4.A: Wave Properties
ESS1.C: History of Planet Earth	ESS1.A: The Universe and Its Stars ESS1.B: Earth & the Solar System
ESS2.E: Biogeology	ESS2.A: Earth Materials ESS2.B: Plate Tectonics & Large-Scale System Interactions

As with the other models, these suggested connections may merely be a springboard for local curriculum design. They also do not attempt to explicitly assign or connect the engineering design PEs since connecting them to particular science domains or concepts is a very individualized decision based on a host of local factors.

Implementing multiple approaches: Nothing in this approach is incompatible with the curriculum-narrowing approaches described elsewhere. Concurrently or sequentially offered courses could deviate from the NGSS Appendix K model by narrowing their focus in the same way that accelerated models might be narrowed.

Considerations for Advanced Placement (AP) in the ANMCM

Process and Assumptions: How Was This Section Developed?

Creating the accelerated conceptual course maps was the first step in the process of creating accelerated model course pathways, and for some districts those models alone may provide sufficient guidance. However, these course maps ignore the commonality of science concepts between the NGSS and many upper-level science courses, including AP courses. Given the number of shared concepts, a guide for how the shared conceptual ideas are addressed between the sets of standards is an essential tool for improving the instructional efficiency of the accelerated pathway(s) offered by allowing the option of reducing instructional redundancy.

To that end, the content in the NGSS was compared to the content in the AP science course guides to identify areas of conceptual similarity. AP courses were used as an example of upper-level science courses for this comparison because they are used widely throughout the country and have a consistent course structure. For this example comparison, the specific language of each AP essential knowledge (AP EK) statement was compared to the DCI elements associated with each NGSS PE to determine whether the two share similar content or a conceptual foundation. In most cases, the NGSS content builds a thorough foundation for the concepts in the AP EK statements. In areas where the NGSS and the AP EK statements overlap significantly, the overlap is rarely complete because the NGSS are written for all students at the high school level, whereas AP EK statements are meant to cover college-level content. Consequently, the comparisons and overlaps are not one-to-one and instead illustrate how the NGSS form a foundation for the college-level concepts addressed in the AP science courses. In the individual charts appended to this document, a general description of the overlap is provided, along with any exceptions to this scenario.

While the structure of the NGSS places equal importance on content, practices, and CCCs, the AP science course guides emphasize content and practices. Both sets of standards have expectations for student performance, but their structures are not the same. In the NGSS, each PE is constructed with a practice, disciplinary content, and a CCC. In the AP course guides, the learning objectives, which could be likened to the NGSS PEs, combine content with reasoning and inquiry skills from the AP science practices.

Like the NGSS PEs, the AP learning objectives clearly articulate what students should know by the end of a course and allow teachers to see how practices and content work together when integrated. However, the AP learning objectives do not include a dimension for the CCCs that are found in the NGSS.

Although the AP course guides do not have an explicit and separate group of CCCs, the content and many learning objectives integrate CCCs similar to the ones seen in the NGSS. For example, in AP Biology, Learning Objective 1.1 includes the concept of cause and effect. Other learning objectives in the AP science course guides have students analyze and identify patterns and relationships between different groups, look at the movement of matter and energy, and work with systems. Since CCCs are not explicitly pulled out and identified in the AP course guides and are not consistently integrated with every AP learning objective, the comparison process described in this document does not include the overlaps in the CCCs that may exist between the two sets of standards. This does not mean that overlaps do not exist but rather that the overlaps do not lend themselves to one-to-one comparisons because of their structures.

Similarly, the science practices found in each set of standards were not included in the comparison process due to differences in their structures and content. The NGSS identifies eight practices for science and engineering that are essential for students to learn and engage in. Each practice has several elements that build in complexity and depth across grades. The AP science courses highlight seven practices and emphasize the importance of integrating them with content. Each AP science practice also has multiple parts, but there is no grade progression since an AP science course is meant to be taught in one grade level. When looking at the NGSS and AP practices side by side, there are both similarities and differences in terms of the actual practices. For example, both sets of standards ask students to use models to communicate scientific phenomena, engage in scientific questioning, analyze and evaluate data, and conduct investigations. However, the AP courses do not explicitly separate out the practices of argument and explanation, as is the case in the NGSS. Instead, AP incorporates the components of the argument practice with explanation into Science Practice 6 (the student can work with scientific explanations and theories) in part 6.1 (the student can justify claims with evidence). Although the practices overlap and both the NGSS and AP emphasize the importance of integrating practices with content, the overlaps do not lend themselves to one-to-one comparisons because the structure, content, and integration of the practices into the learning objectives differ.

Due to the nature of the difference in format and content emphasis between the NGSS and the AP course guides, particularly the emphasis in the NGSS on three dimensions and their components found in the foundation boxes, the comparison in this document focuses solely on the overlap of disciplinary content rather than on any similarities related to the practices or CCCs. When comparing the AP EK content to the NGSS, not all components of the PE were evaluated. Only the DCI elements associated with each PE were used in the comparison, and the PE code is included in the tables and appended charts as a reference point to these DCI elements. This is not to be taken as a devaluation of the practices or CCCs but rather solely reflects the fact that the AP course guides themselves tend to emphasize content that more closely aligns with the DCIs.

The comparison process described above was undertaken using three AP course guides: AP Biology, AP Chemistry, and AP Physics 1 and 2. Appendices A, B, and C include the three comparison charts, one for each AP course, that were produced as a result of the comparison process. The charts are organized by the AP EK statements and include any NGSS DCI elements that overlap with and/or build a foundation for the AP content in each AP EK statement. AP EK statements are not included in the course chart if no direct connections were found between them and the NGSS content. Similarly, NGSS PEs and DCIs are not included in the course charts if no similarity was found between them and the AP content. The comments in each AP EK statement row include a general description of the content similarity between the two sets of standards. Each AP comparison chart is also accompanied by a quick reference comparison grid that illustrates the connections between the AP course and the NGSS, using the NGSS PE codes to stand in for the associated DCI content.

The following tables — Table 3A, 3B, and 3C — are simplified versions of the course charts in Appendices A, B, and C. The tables show the AP EK statements and possible corresponding NGSS PEs that build toward them for each AP course. Once again, it is important to note that the actual PEs were not used in the comparison process for the reasons described above, unless otherwise indicated in the chart comments. The table and the appended course charts include the PE code so that it easier to identify the DCI elements that overlap with or provide a foundation for the AP EK statements.

The charts and tables are not meant to limit or dictate curriculum. They illustrate content and conceptual overlaps between AP science courses and the NGSS to allow educators to more easily provide connections between the two sets of standards. It is important to note that the connections outlined in the appended charts are not the only connections that can be made between the NGSS and the AP science courses. Because of the coherence in the NGSS, relationships can be found across multiple disciplines. For simplicity, the charts reflect only the most related aspects.

Teachers can use these connections when designing curricula for foundational NGSS-aligned courses and for AP science courses, and the comparisons are only one contributing piece to the overall curriculum design process. Using this information, districts can begin to strategically consider connections between courses and may choose to modify the accelerated course maps described earlier in this document to suit the particular combination of circumstances, staff, certifications, and AP course offerings unique to their circumstances. An example of how this information can be useful to teachers can be found on page 33.

A note regarding AP Physics: For the purposes of this document, the comparison was done only for AP Physics 1 and AP Physics 2, which are the equivalent of introductory, algebra-based college physics courses. The College Board combines the full course descriptions for both introductory physics courses into one course guide, and accordingly, the comparison between the NGSS and both AP Physics courses was done in one chart. The appendices and corresponding charts indicate which AP Physics course is referenced when looking at the overlaps with the NGSS. The chart differentiates between content in the two courses by using “P1” for AP Physics 1 and “P2” for AP Physics 2. For students taking only one AP Physics course, careful attention needs to be paid to the conceptual similarity in that specific course rather than the entire chart. The College Board’s other two AP physics courses, AP Physics C: Mechanics and AP Physics C: Electricity and Magnetism, were not evaluated.

A note regarding AP Environmental Science: The AP Environmental Science course guide has yet to undergo the same level of revision by the College Board as have the course guides for AP Biology, Chemistry, and Physics. Since the current AP Environmental Science course guide does not contain the level of detail as the other revised subject guides, a substantial comparison cannot be made, and this course was not evaluated.

Table 3A: AP Biology Comparison

The table below organizes the middle and high school NGSS PEs that overlap with or form a foundation for content taught in the AP Biology course as described in the AP EK statements. It is important to note that not all of the components of each PE were considered in the overlap. Only the DCI elements associated with each PE were compared to the AP EK statements, and the PE codes are included as a reference to these DCI elements.

AP EK	NGSS PE(s)
1.A.1	HS-LS2-6, HS-LS3-2, HS-LS3-3, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-5
1.A.2	HS-LS2-7, HS-LS3-2, HS-LS3-3, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-6
1.A.4	HS-LS4-1, HS-ESS1-5
1.B.2	HS-LS4-1
1.C.1	HS-LS2-7, HS-LS4-5
1.C.2	HS-LS4-4, HS-LS4-5
1.C.3	HS-LS4-1, HS-LS4-5
1.D.2	HS-ESS1-6
2.A.1	HS-LS1-7, HS-LS2-4, HS-PS1-4, HS-PS3-4
2.A.2	MS-LS1-2, HS-LS1-5, HS-LS1-6, HS-LS1-7, HS-LS2-3, HS-PS1-4, HS-PS3-2
2.A.3	HS-LS1-6, HS-LS2-5, HS-ESS2-5
2.B.1	MS-LS1-2, HS-PS1-3
2.B.2	MS-LS1-2, HS-PS3-4
2.B.3	MS-LS1-2
2.C.1	HS-LS1-3
2.C.2	HS-LS1-3
2.D.1	HS-LS2-1, HS-LS2-2, HS-LS2-4, HS-LS2-6
2.D.3	HS-LS2-6, HS-LS2-7, HS-LS4-6
2.E.1	HS-LS1-4, HS-LS3-1, HS-LS3-2
2.E.3	HS-LS2-8, HS-LS4-5
3.A.1	HS-LS1-1, HS-LS3-1, HS-LS3-2
3.A.2	MS-LS3-2, HS-LS1-4, HS-LS3-1, HS-LS3-2
3.A.3	MS-LS3-2, HS-LS3-1, HS-LS3-2
3.B.1	HS-LS1-4, HS-LS3-1
3.B.2	HS-LS1-4
3.C.1	MS-LS3-1, HS-LS3-2, HS-LS4-3
3.C.2	HS-LS3-2
3.D.2	MS-LS1-8
3.E.1	HS-LS2-8, HS-LS4-3

3.E.2	MS-LS1-8, HS-LS1-2, HS-PS3-5
4.A.1	HS-LS1-1, HS-LS1-6, HS-PS2-6
4.A.2	MS-LS1-2, HS-LS1-5
4.A.3	HS-LS1-1, HS-LS1-2, HS-LS1-4, HS-LS3-1, HS-LS3-3
4.A.4	HS-LS1-2
4.A.5	MS-LS2-2, HS-LS2-1, HS-LS2-2, HS-LS2-6, HS-LS2-7, HS-LS4-6, HS-ESS3-5, HS-ESS3-6
4.A.6	HS-LS2-1, HS-LS2-2, HS-LS2-4, HS-LS2-5, HS-LS2-7, HS-LS4-6, HS-ESS3-6
4.B.1	HS-PS2-6
4.B.2	MS-LS1-2, HS-LS1-1, HS-LS1-2
4.B.3	MS-LS2-2, HS-LS2-2, HS-LS2-6, HS-LS2-7, HS-LS2-8, HS-LS4-6
4.B.4	HS-LS2-7, HS-LS4-6, HS-ESS2-2, HS-ESS3-1, HS-ESS3-6
4.C.1	MS-LS3-2
4.C.2	HS-LS3-3
4.C.3	HS-LS3-3, HS-LS4-5
4.C.4	HS-LS2-2, HS-LS4-5

Table 3B: AP Chemistry Comparison

The table below organizes the middle and high school NGSS PEs that overlap with or form a foundation for content taught in the AP Chemistry course as described in the AP EK statements. It is important to note that not all of the components of each PE were considered in the overlap. Unless otherwise stated in the comment section in Appendix B, only the DCI elements associated with each PE were compared to the AP EK statements, and the PE codes are included as a reference to these DCI elements.

AP EK	NGSS PE(s)
1.A.1	MS-PS1-1
1.A.3	HS-PS1-6, HS-PS1-7
1.B.1	HS-PS1-1, HS-PS2-4
1.B.2	HS-PS1-1, HS-PS1-2, HS-PS2-4
1.C.1	HS-PS1-1
1.C.2	HS-PS2-4
1.D.1	HS-PS1-1, HS-PS1-3
1.D.3	HS-PS3-5, HS-PS4-5, HS-ESS1-2
1.E.1	HS-PS1-2, HS-PS1-7, HS-ESS2-6, HS-LS2-4, HS-LS2-5
1.E.2	HS-PS1-2, HS-PS1-7
2.A.1	MS-PS1-4, HS-PS1-1, HS-PS1-3, HS-PS2-6, HS-PS3-2
2.A.2	MS-PS1-4, HS-PS1-3, HS-PS2-4, HS-PS2-6, HS-PS3-2, HS-PS3-4, HS-PS3-5
2.A.3	HS-PS1-4, HS-PS2-6
2.B.3	HS-PS1-1, HS-PS1-3, HS-PS2-6, HS-PS3-2
2.C.1	HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS1-4, HS-PS2-4, HS-PS3-2, HS-PS3-5
2.C.2	HS-PS1-1, HS-PS1-3, HS-PS1-4, HS-PS2-4, HS-PS2-6, HS-PS3-5
2.C.3	HS-PS1-1, HS-PS2-4
2.D.1	HS-PS1-1, HS-PS1-3, HS-PS2-4, HS-PS2-6
2.D.2	HS-PS1-1, HS-PS1-3, HS-PS2-4, HS-PS2-6
2.D.3	HS-PS1-1, HS-PS1-3, HS-PS2-4, HS-PS2-6
2.D.4	HS-PS1-1, HS-PS1-3, HS-PS2-4, HS-PS2-6
3.A.1	HS-PS1-6, HS-PS1-7
3.A.2	HS-PS1-7
3.B.1	HS-PS1-2
3.C.1	HS-PS1-1, HS-PS1-2, HS-PS1-4
3.C.2	HS-PS1-4, HS-PS3-1, HS-PS3-2
3.C.3	HS-PS3-1, HS-PS3-3, HS-PS3-5
4.A.1	HS-PS1-5, HS-PS3-2

4.A.3	HS-PS1-5, HS-PS3-2
4.B.2	HS-PS1-4
4.B.3	HS-PS1-4, HS-PS1-5, HS-PS3-5
5.A.1	MS-PS3-3, HS-PS3-2, HS-PS3-4
5.A.2	HS-PS3-2, HS-PS3-4
5.B.1	HS-PS3-1, HS-PS3-2, HS-PS3-3, HS-PS3-4
5.B.2	HS-PS3-1, HS-PS3-4
5.B.3	HS-PS1-3, HS-PS1-4, HS-PS3-1, HS-PS3-2
5.B.4	MS-PS3-4, HS-PS3-4
5.C.1	HS-PS1-3, HS-PS1-4, HS-PS3-2, HS-PS3-5
5.C.2	HS-PS1-4, HS-PS3-3, HS-PS3-4
5.D.1	HS-PS1-3, HS-PS1-4, HS-PS2-4, HS-PS3-2, HS-PS3-5
5.D.2	HS-PS1-2, HS-PS1-4
5.D.3	HS-PS1-3, HS-PS2-6, HS-LS1-6
5.E.1	HS-PS3-1, HS-PS3-2, HS-PS3-4
6.A.1	HS-PS1-6
6.A.3	HS-PS1-6, HS-PS3-4
6.A.4	HS-PS1-2, HS-PS1-6
6.B.1	HS-PS1-6
6.C.3	HS-PS1-6

Table 3C: AP Physics 1 and 2 Comparison

The table below organizes the middle and high school NGSS PEs that overlap with or form a foundation for content taught in the AP Physics 1 and 2 courses as described in the AP EK statements. It is important to note that not all of the components of each PE were considered in the overlap. Only the DCI elements associated with each PE were compared to the AP EK statements, and the PE codes are included as a reference to these DCI elements.

AP EK	NGSS PE(s)
1.A.3	HS-PS1-1, HS-PS1-8
1.A.4	HS-PS1-1, HS-PS1-3, HS-ESS1-2
1.A.5	HS-PS1-3
1.B.2	MS-PS2-3, HS-PS2-4, HS-PS3-5
1.C.1	MS-PS2-2, HS-PS2-1
1.C.2	MS-PS2-4, HS-PS2-1, HS-PS2-4
1.D.2	HS-PS3-3, HS-PS3-4
1.E.1	MS-PS1-2
1.E.2	HS-PS1-1, HS-PS1-3, HS-PS2-6
1.E.3	HS-PS1-1, HS-PS1-3, HS-PS2-6
1.E.4	HS-PS1-1
2.A.1	MS-PS2-5, HS-PS2-4
2.A.2	HS-PS2-4
2.B.1	HS-PS2-4
2.B.2	HS-PS2-4
2.C.1	MS-PS2-3, HS-PS2-4
2.C.2	HS-PS2-4
2.C.3	HS-PS2-4
2.D.1	HS-PS2-5
2.D.2	HS-PS2-5
3.A.1	MS-PS2-2, HS-PS2-1, HS-PS2-2
3.A.2	MS-PS2-2, HS-PS2-1
3.A.3	MS-PS2-1
3.A.4	MS-PS2-1
3.B.1	MS-PS2-1, HS-PS2-1
3.C.1	MS-PS2-4, HS-PS2-4
3.C.2	HS-PS2-4
3.C.3	MS-PS2-5
3.D.1	HS-PS2-2, HS-PS2-3
3.D.2	HS-PS2-2, HS-PS2-3
3.E.1	MS-PS3-1, MS-PS3-2, MS-PS3-5, HS-PS3-1, HS-PS3-5
3.G.1	MS-ESS1-2, HS-PS2-4, HS-ESS1-4

3.G.2	HS-PS2-4, HS-PS4-3
3.G.3	HS-PS1-8, HS-ESS1-1, HS-ESS1-3
4.A.1	MS-PS2-1, MS-PS2-2, HS-PS2-1, HS-PS2-2
4.A.2	MS-PS2-1, MS-PS2-2, HS-PS2-1, HS-PS2-2
4.B.1	HS-PS2-2
4.B.2	HS-PS2-2, HS-PS2-3
4.C.1	MS-PS3-2, HS-PS3-2
4.C.2	MS-PS3-5, HS-PS3-5
4.C.3	MS-PS3-3, MS-PS3-4, HS-PS3-4
4.C.4	HS-PS1-8, HS-ESS1-1
4.E.2	HS-PS2-5
5.A.1	HS-PS2-2
5.A.2	HS-PS2-2, HS-PS2-3, HS-PS3-1, HS-PS3-2, HS-PS3-3
5.B.1	HS-PS3-2
5.B.2	HS-PS3-1, HS-PS3-2
5.B.3	MS-PS3-2, HS-PS3-1, HS-PS3-2
5.B.4	MS-PS3-4, HS-PS3-1, HS-PS3-2
5.B.5	HS-PS3-1, HS-PS3-3, HS-PS3-5
5.B.6	MS-PS3-3, MS-PS3-4, HS-PS3-4
5.D.1	HS-PS2-2, HS-PS2-3
5.D.2	HS-PS2-2, HS-PS2-3
5.G.1	HS-PS1-8
6.A.2	MS-PS4-2, HS-PS4-1
6.A.3	MS-PS4-1
6.A.4	MS-PS4-1
6.B.1	MS-PS4-1, HS-PS4-1
6.B.2	MS-PS4-1, HS-PS4-1
6.B.3	MS-PS4-1, HS-PS4-1
6.E.1	MS-PS4-2, HS-PS4-4
6.E.2	MS-PS4-2
6.E.3	MS-PS4-2
6.F.1	HS-PS4-1, HS-PS4-3, HS-PS4-4
6.F.2	HS-PS4-1
6.F.3	HS-PS4-3
6.F.4	HS-PS4-3

Using the Considerations for AP

The considerations for AP can be used in two ways:

1. Complete instructional separation between foundational NGSS-aligned courses and AP courses.
2. Consideration of the overlaps between foundational NGSS-aligned courses and AP courses when designing curriculum.

1. Complete instructional separation between foundational NGSS-aligned courses and AP courses.

Schools and districts employing this approach could require that every NGSS PE be taught to mastery in one of the accelerated models described in this document, with all NGSS PEs included as written. The NGSS would be taught in its entirety before students begin AP coursework. Some reasons a district or school might choose this approach include: the inability to coordinate between the high school and the feeder middle school(s), difficulty logistically coordinating curriculum between AP courses and foundational courses, or transient or frequent student transfer issues among or across schools/districts. This approach might also be necessary if there is a large-scale summative assessment of the NGSS administered to all students prior to their entry into AP courses.

Benefits of this approach:

- It does not rely on collaboration among faculty, so there is no chance of an introduced "gap" between the foundational courses and AP courses.
- Students will have repeated exposure to some concepts and therefore have greater opportunities for deep learning.
- There is a potential of differing context for shared learning, thereby broadening opportunities for transfer.
- The potential for conflict with NGSS-based assessment/accountability systems is reduced because all instruction of NGSS content would have occurred by the end of the second year of high school at the latest.

Limitations of this approach:

- Repeated exposure to the same concepts may be instructionally inefficient for some students and may contribute to instructional fatigue if students perceive that they are learning the same concepts twice.
- It may not be the most efficient use of staff and course time for schools and districts since it requires scheduling and staffing two essentially separate science course "clusters."
- It may contribute to a perception that foundational teachers are not valued to the same degree as are AP teachers since AP courses address concepts that were already fully or partially learned in the foundational courses.

2. Consideration of the overlaps between foundational NGSS-aligned courses and AP courses when designing curriculum.

Schools and districts employing this approach could use the accompanying correlations between the NGSS and AP courses when designing curriculum for one or both sets of courses. The appended charts describe connections between the two sets of standards. Taking these content connections into consideration could allow foundational NGSS teachers and AP teachers to make strategic decisions about their course structures. Some possible ways educators might decide to use the content connections include:

- Planning the foundational and AP courses such that they will expose students to the same concepts in different contexts, allowing for concept reinforcement.
- Structuring the AP courses around what students already know and what they need to be able to do at the end of the AP course, maximizing instructional efficiency.
- Reducing the instructional coverage of shared concepts in AP courses with the understanding that the foundational NGSS-aligned courses have already addressed certain foundational concepts in sufficient depth that they need not be duplicated.

Consideration of the content overlaps can be particularly helpful to AP teachers since they know what foundational concepts students are coming into their classrooms with. Teachers of foundational science courses will not necessarily know which AP courses (if any) students will choose to take.

Benefits of this approach:

- It maximizes instructional efficiency of the school as a whole since more science content can be incorporated.
- It can offer the benefit of learning "duplicated" content in differing contexts in different courses.

Limitations of this approach:

- It can require coordination and/or joint curriculum design among the NGSS foundational course teachers and AP teachers.
- It requires changes to the AP course instructional plans, which may already be set in place.

Example of a Chart Comparison

Table 4 is an example from the appended comparison charts, which were created through the comparison process. This particular example shows a comparison between the NGSS and EK Statement 1.C.1 from the AP Chemistry course.

To understand the comparison process, it is important to be familiar with the structure and organization of both the NGSS and the AP science courses that were evaluated. Each of the three AP science course guides compared are organized around "Big Ideas," the key principles in each course. Each Big Idea has several enduring understandings (EUs) that reflect the core concepts students should learn from the AP course, and each EU is supported by EK statements. Most of the EK statements have a main statement and then several supporting, detailed parts. Other EK statements simply consist of the main statement. Although all parts of an EK statement were evaluated during the comparison process, for simplicity, Table 4 and the appended charts contain only the main statements for each EK, regardless of whether it has supporting parts.

The code for each EU includes a numeral component that indicates the Big Idea that the EU supports and a letter that identifies the EU statement. Similarly, each EK code identifies the EK's associated Big Idea, EU, and a number designating that particular EK statement. In the example in Table 4, AP EU 1.C refers to Enduring Understanding C in Big Idea 1. EK 1.C.1 belongs in Big

Idea 1 and Enduring Understanding 1.C, and it is the first EK statement for its EU — therefore, its code is 1.C.1.

The NGSS consist of three dimensions: the SEPs, DCIs, and CCCs. The NGSS PEs are statements of what students should know and be able to do, and every PE consists of a SEP, DCIs, and a CCC. As discussed in the "Processes and Assumptions" section of this document, the content in the AP EK statements was compared to the content in the NGSS DCIs to determine whether the two standards share similar content or a conceptual foundation. The SEP and CCC components of the PEs were not compared because they did not lend themselves to one-to-one comparisons between documents.

Table 4 shows a comparison between AP Chemistry EK statement 1.C.1 and the NGSS. The first column in Table 4 lists the AP EU code and text associated with the AP EK statement being evaluated. The EU is included as a reference point for the EK statement and to show the overall concept that the EK content falls under. The second column includes the AP EK code and main statement. Although all parts of the EK statement were evaluated in the comparison process, this figure includes only the text from the main statement. The full EK text can be found in the course description guides on the College Board website. The EK statements were chosen in the comparison process because they contain the specific content that most closely resembles the NGSS DCIs.

The EK statements were compared for overlaps with the DCI elements associated with NGSS PEs. The third column identifies the NGSS DCI element(s) that overlap with or provide a foundation for the AP EK statements. This column includes only the relevant parts of the DCI elements that show an overlap with the content in the AP EK statements. The fourth column lists the NGSS PEs that contain the identified DCI elements. The fifth and last column includes comments about the identified overlaps. The comments briefly describe the content similarities and dissimilarities between the two sets of standards.

Given the content connections outlined in the charts, teachers could plan modifications to the instructional design for their AP courses. In the Table 4 example, the comparison shows that the NGSS and AP both describe the periodicity of the elements. The teacher therefore knows what foundational knowledge students should be coming into their AP courses with. They could choose to spend less time on the basic concept of how elements are organized in the periodic table and instead focus on applying this knowledge in different contexts, reducing content redundancy and allowing for deeper learning and reinforcement. These instructional decisions will be unique to each context and circumstance.

Table 4: NGSS and AP Chemistry Comparison Example

The figure below is an example of the comparison between the content in the NGSS and AP Chemistry, and it is pulled from the AP Chemistry Chart in Appendix B.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments
1.C Elements display periodicity in their properties when the elements are organized according to increasing atomic number. This periodicity can be explained by the regular variations that occur in the electronic structures of atoms. Periodicity is a useful principle of understanding properties and predicting trends in properties. Its modern-day uses range from examining the composition of materials to generating ideas for designing new materials.	**1.C.1** Many properties of atoms exhibit periodic trends that are reflective of the periodicity of electronic structure.	**HS.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. 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.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.	**HS-PS1-1** 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.	Both **NGSS HS.PS1.A** and **AP EK 1.C.1** describe periodicity of the elements. AP EK 1.C.1 includes additional details about electron shells, ionization energy, and atomic radii that are not included in the NGSS.

How a District or School Might Use This Information

Small districts or small schools within a larger district: Districts with smaller student populations intending to pursue advanced coursework would likely choose to implement individual accelerated course sections in middle school. In this case, small is defined as a school with a number of accelerated students not large enough to be allocated a full instructional load of science course sections following the accelerated pathway. In middle school, the accelerated course(s) could be taught by the same teachers who teach the non-accelerated pathway(s), perhaps requiring a separate course preparation and the schedules of all of the accelerated students to "converge" into the same course(s) in science. Since it is a likely assumption that students pursuing an accelerated science pathway will do the same in mathematics and perhaps other subjects, the most efficient scheduling decision might be for those students to travel together as a group following the same accelerated schedule during the instructional day.

Since teachers in this model do dual duty by teaching both standard and accelerated courses, the instructional sequences of both could be synchronized to share as much instructional time/concepts/material preparation as possible. These scheduling decisions are likely less complicated at the high school level since high school scheduling is usually more flexible and better able to accommodate the scheduling of discrete courses than are traditional middle school schedules, in which a teacher often teaches the same preparation all day.

Large districts or large schools: The very largest of schools (or perhaps STEM magnet schools) may have enough students intending to pursue advanced coursework to require assignment of a full accelerated course load (or schedule equivalent) to a single teacher or teacher equivalent. For those few schools able to employ it, this approach would possibly allow a program of similar acceleration to be implemented for other subject areas concurrently. Students with an interest in advanced coursework in science also are likely to pursue advanced courses in mathematics and other subjects as well.

Since a fundamental assumption of these models is that middle schools could be involved in the accelerated pathways, these models are more useful to districts than to individual high schools. Feeder schools (either single or multiple) must be part of the conversation to use these models because of the assumption that the responsibility for teaching NGSS high school PEs begins prior to 9th grade.

Limitations: As was mentioned in the NGSS Appendix K, the term "courses" may be an unnecessarily limiting definition that privileges a system based on seat time. Some teachers, schools, districts, and states are moving toward a proficiency-based system. Yet even in such a situation, these model course maps can help guide conversations about the connections between NGSS PEs, at least for those foundational courses in which innovative approaches are being implemented.

Most of the recommendations and discussion for the "Next Steps for Course Map 1" from pages 13–14 of the NGSS Appendix K (except perhaps step 6) also apply to any models derived from this document. As districts gain experience implementing courses informed by these pathways, sequencing and allocation of instructional responsibility undoubtedly will need to be adjusted or perhaps even PEs moved across grade levels. Issues of certification arising from faculty transitions might also necessitate revising some portions of the accelerated pathways.

Conclusion

This document shows possible pathways for accelerated students to follow so that they can meet the NGSS and also have the ability to take multiple AP courses. To reiterate, the ANMCM are not intended to be a means for all students to complete science learning in a condensed number of years but rather are intended to be used for those students who have the intention of furthering their science education in high school through an extremely rigorous accelerated program cumulating with one or more advanced course(s). Many of the questions in the "Factors for Consideration" from the NGSS Appendix K (pp. 34–39) apply to the models and approach presented herein. Rather than repeat those factors, readers are urged to consult the NGSS Appendix K to determine what guidance from that document also might be helpful in informing their decisions as they develop accelerated pathways to meet their individual needs.

Development Process

To write the ANMCM, discipline-based teams of AP educators — including some of the writers of the NGSS — worked together to identify methods of acceleration and then drafted charts to show the conceptual similarities between the NGSS and AP. Additional educators, state science supervisors, and disciplinary specialists then provided feedback on the draft narrative and accompanying appendices.

Acknowledgments

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APPENDIX A
NGSS & AP Biology Comparison Chart

What was evaluated and compared?

- For this comparison, the specific language of each AP Essential Knowledge (AP EK) statement was compared to the Disciplinary Core Idea (DCI) elements associated with each Next Generation Science Standards (NGSS) Performance Expectation (PE) to determine whether the two share a similar content or conceptual foundation.
- The NGSS and the AP course guides are very different in intended format, audience (the NGSS is for all students whereas the AP course guides cover college-level content), and content emphasis, particularly the emphasis in the NGSS on all three components of the foundation boxes. Therefore, this document focuses solely on the overlap of disciplinary content rather than on any similarities related to the practices or crosscutting concepts. When comparing the AP EK content to the NGSS, only the DCI elements associated with each PE were used in the comparison. This is not to be taken as a devaluation of the practices or crosscutting concepts. A discussion of practices and crosscutting concepts can be found on page 23.

How is the chart organized?

- The charts are organized by the AP EK statements and include some possible DCI elements that overlap with or build a foundation for the AP content in each EK statement. AP EK statements are not included in the course chart if no similarity was found between them and the NGSS content.
- The entirety of the EK text is not included in each row. Most EK statements have a general statement and then multiple supporting parts for the statement. While all parts of the EK text were evaluated for the comparison, the chart only includes the general EK statement. Where appropriate, the comments in each row refer to individual parts of the EK text. For the full EK text, please see the AP Biology Course and Exam Description from College Board.
- The full text for each identified DCI is not included in the chart. Only the DCI elements that overlap with or provide a foundation for the AP EK statements are included in the chart.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.A Change in the genetic makeup of a population over time is evolution.	**1.A.1** Natural selection is a major mechanism of evolution.	**HS.LS2.C: Ecosystem Dynamics, Functioning, and Resilience** A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. **HS.LS3.B: Variation of Traits** In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited. Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors. **HS.LS4.B: Natural Selection** Natural selection occurs only if there is both (1) variation in the genetic information between organisms in a population and (2) variation in the expression of that genetic information—that is, trait variation—that leads to differences in performance among individuals. The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population. **HS.LS4.C: Adaptation** Evolution is a consequence of the interaction of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment. *(continued on next page)*	**HS-LS2-6** Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. **HS-LS3-2** Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors. **HS-LS3-3** Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population. **HS-LS4-2** Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment. **HS-LS4-3** Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait. *(continued on next page)*	The NGSS build a foundation for students to understand the theory of natural selection and how it is a mechanism for evolution. **AP EK 1.A.1** goes beyond the NGSS by including details about how environmental conditions can affect evolutionary rate and direction, the Hardy-Weinberg equilibrium, and the mathematical calculations involved for changes in allele frequency.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
	1.A.1 Natural selection is a major mechanism of evolution.	Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not. Adaptation also means that the distribution of traits in a population can change when conditions change. Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline–and sometimes the extinction–of some species. Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or drastic, the opportunity for the species' evolution is lost.	**HS-LS4-4** Construct an explanation based on evidence for how natural selection leads to adaptation of populations. **HS-LS4-5** Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.	

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.A Change in the genetic makeup of a population over time is evolution.	**1.A.2** Natural selection acts on phenotypic variations in populations.	**HS.LS2.C: Ecosystem Dynamics, Functioning, and Resilience** Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. **HS.LS3.B: Variation of Traits** In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited. Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors. **HS.LS4.B: Natural Selection** Natural selection occurs only if there is both (1) variation in the genetic information between organisms in a population and (2) variation in the expression of that genetic information—that is, trait variation—that leads to differences in performance among individuals. The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population. **HS.LS4.C: Adaptation** Evolution is a consequence of the interaction of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment. Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not. *(continued on next page)*	**HS-LS2-7** Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.* **HS-LS3-2** Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors. **HS-LS3-3** Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population. **HS-LS4-2** Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment. **HS-LS4-3** Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait. *(continued on next page)*	The NGSS and AP both describe how variations in traits can occur, how environmental factors can act as selective mechanisms, and how the variations can affect the fitness of an organism. **NGSS HS.LS2.C** and **HS.LS4.D** and **AP EK 1.A.2 part d** describe how humans can impact species, but part d focuses specifically on human impact on variation in a species.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
	1.A.2 Natural selection acts on phenotypic variations in populations.	Adaptation also means that the distribution of traits in a population can change when conditions change. Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline–and sometimes the extinction–of some species. **HS.LS4.D: Biodiversity and Humans** Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.	**HS-LS4-4** Construct an explanation based on evidence for how natural selection leads to adaptation of populations. **HS-LS4-6** Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.*	
1.A Change in the genetic makeup of a population over time is evolution.	**1.A.4** Biological evolution is supported by scientific evidence from many disciplines, including mathematics.	**HS.LS4.A: Evidence of Common Ancestry and Diversity** Genetic information, like the fossil record, provides evidence of evolution. DNA sequences vary among species, but there are many overlaps; in fact, the ongoing branching that produces multiple lines of descent can be inferred by comparing the DNA sequences of different organisms. Such information is also derivable from the similarities and differences in amino acid sequences and from anatomical and embryological evidence. **HS.ESS1.C: The History of Planet Earth** Continental rocks, which can be older than 4 billion years, are generally much older than the rocks of the ocean floor, which are less than 200 million years old. **HS.ESS2.B: Plate Tectonics and Large-Scale System Interactions** Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history. **HS.PS1.C: Nuclear Processes** 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.	**HS-LS4-1** Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence. **HS-ESS1-5** Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.	The NGSS and AP both describe the scientific evidence that supports biological evolution, including radioactive dating. **AP EK 1.A.4** goes beyond the NGSS by including details on mathematical models and simulations that can support evolution.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.B Organisms are linked by lines of descent from common ancestry.	**1.B.2** Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested.	**HS.LS4.A: Evidence of Common Ancestry and Diversity** Genetic information, like the fossil record, provides evidence of evolution. DNA sequences vary among species, but there are many overlaps; in fact, the ongoing branching that produces multiple lines of descent can be inferred by comparing the DNA sequences of different organisms. Such information is also derivable from the similarities and differences in amino acid sequences and from anatomical and embryological evidence.	**HS-LS4-1** Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.	**NGSS HS.LS4.A** sets the foundation for students to learn about phylogenetic trees and cladograms in **AP EK 1.B.2** by describing the evidence for evolution and introducing the graphical representations through the "ongoing branching that produces multiple lines of descent."
1.C Life continues to evolve within a changing environment.	**1.C.1** Speciation and extinction have occurred throughout the Earth's history.	**HS.LS2.C: Ecosystem Dynamics, Functioning, and Resilience** Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. **HS.LS4.C: Adaptation** Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline–and sometimes the extinction–of some species. Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or drastic, the opportunity for the species' evolution is lost. **HS.LS4.D: Biodiversity and Humans** Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.	**HS-LS2-7** Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.* **HS-LS4-5** Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.	Both the NGSS and AP include the concepts of speciation and extinction. **NGSS HS.LS4.C** builds the foundation for **AP EK 1.C.1** which goes beyond the NGSS by including details about the rates of speciation and extinction. **NGSS HS.LS2.C** and **HS.LS4.D** are similar to EK 1.C.1 **part b** in its description of how human activity can affect species extinction.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.C Life continues to evolve within a changing environment.	**1.C.2** Speciation may occur when two populations become reproductively isolated from each other.	**HS.LS4.C: Adaptation** Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not. Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline–and sometimes the extinction–of some species. Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or drastic, the opportunity for the species' evolution is lost.	**HS-LS4-4** Construct an explanation based on evidence for how natural selection leads to adaptation of populations. **HS-LS4-5** Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.	**NGSS HS.LS4.C** sets the foundation for **AP EK 1.C.2** by describing how changes in the physical environment can lead to the divergence of species. EK 1.C.2 goes beyond the NGSS by including details about the physical separation and pre- and post-zygotic mechanisms that can result in reproductive isolation, and by including details about the rate of speciation.
1.C Life continues to evolve within a changing environment.	**1.C.3** Populations of organisms continue to evolve.	**HS.LS4.A: Evidence of Common Ancestry and Diversity** Genetic information, like the fossil record, provides evidence of evolution. DNA sequences vary among species, but there are many overlaps; in fact, the ongoing branching that produces multiple lines of descent can be inferred by comparing the DNA sequences of different organisms. Such information is also derivable from the similarities and differences in amino acid sequences and from anatomical and embryological evidence. **HS.LS4.C: Adaptation** Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline–and sometimes the extinction–of some species. Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or drastic, the opportunity for the species' evolution is lost.	**HS-LS4-1** Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence. **HS-LS4-5** Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.	Both AP and the NGSS state that there is scientific evidence that supports evolution.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.D The origin of living systems is explained by natural processes.	**1.D.2** Scientific evidence from many different disciplines supports models of the origin of life.	**HS.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. **HS.PS1.C: Nuclear Processes** 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.	**HS-ESS1-6** 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.	The NGSS set the foundation for understanding how the rocks on Earth or objects in the solar system can provide information about Earth's early history. **AP EK 1.D.2** goes beyond the NGSS by including details about the origin of life and the molecular and genetic evidence that supports existing models for the origin of life.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.A Growth, reproduction and maintenance of the organization of living systems require free energy and matter.	**2.A.1** All living systems require constant input of free energy.	**HS.LS1.C: Organization for Matter and Energy Flow in Organisms** 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. **HS.LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved. **HS.PS1.A: Structure and Properties of Matter** 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.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.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. 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.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-LS1-7** 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. **HS-LS2-4** Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem. **HS-PS1-4** 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. **HS-PS3-4** 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).	**NGSS HS.PS1.A, HS.PS1.B, HS.PS3.B**, and **HS.PS3.D** set the foundation for **AP EK 2.A.1** by describing the conservation of energy, the role of energy in chemical processes, and energy transfer. **NGSS HS.LS1.C** and **HS.LS2.B** continue to build the foundation for AP EK 2.A.1 by integrating this understanding of energy to energy flow in organisms and ecosystems. EK 2.A.1 goes beyond the NGSS by describing how the input of free energy is required for living systems and the effects changes in free energy can have on organisms, populations, and ecosystems.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.A Growth, reproduction and maintenance of the organization of living systems require free energy and matter.	**2.A.2** Organisms capture and store free energy for use in biological processes.	**MS.LS1.A: Structure and Function** Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. **HS.LS1.C: Organization for Matter and Energy Flow in Organisms** The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. 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. 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. **HS.LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. **HS.PS1.A: Structure and Properties of Matter** 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.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. *(continued on next page)*	**MS-LS1-2** Develop and use a model to describe the function of a cell as a whole and ways parts of cells contribute to the function. **HS-LS1-5** Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy. **HS-LS1-6** 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. **HS-LS1-7** 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. **HS-LS2-3** Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions. **HS-PS1-4** 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. *(continued on next page)*	The NGSS and AP both describe the basic role of energy in the processes of photosynthesis and cellular respiration. **AP EK 2.A.2** goes beyond the NGSS by including details about ATP and the flow of energy through the specific steps in the biochemical pathways of photosynthesis and cellular respiration.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
	2.A.2 Organisms capture and store free energy for use in biological processes.	**HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.	**HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).	

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.A Growth, reproduction and maintenance of the organization of living systems require free energy and matter.	**2.A.3** Organisms must exchange the matter with the environment to grow, reproduce and maintain organization.	**HS.LS1.C: Organization for Matter and Energy Flow in Organisms** 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. As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. **HS.LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes. **HS.PS3.D: Energy in Chemical Processes** The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. **HS.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, 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-LS1-6** 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. **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. **HS-ESS2-5** Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.	Both AP and the NGSS include details about the flow of carbon through matter and its integration into hydrocarbon backbones that can be used to build other molecules. While **AP EK 2.A.3 part a.2** explicitly addresses the movement and integration of nitrogen and phosphorus into molecules, the NGSS can also cover the same content about nitrogen and phosphorus when students learn about how "carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules" [PE HS-LS1-6]. **NGSS HS.ESS2.C** and **EK 2.A.3 part a.3** both describe the properties of water, but the NGSS does so in the broader context of the Earth's dynamics and AP does so in the context of living systems. **EK 2.A.3 part b** goes beyond the NGSS by including details about the effect of surface area-to-volume ratios on biological systems.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.B Growth, reproduction and dynamic homeostasis require that cells create and maintain internal environments that are different from their external environments.	**2.B.1** Cell membranes are selectively permeable due to their structure.	**MS.LS1.A: Structure and Function** Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell. **HS.PS1.A: Structure and Properties of Matter** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.	**MS-LS1-2** Develop and use a model to describe the function of a cell as a whole and ways parts of cells contribute to the function. **HS-PS1-3** 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.	**NGSS HS.PS1.A** builds the foundation for understanding the cell membrane's structure and function by including a discussion of polar and non-polar interactions. **NGSS MS.LS1.A** also contributes towards the foundation by introducing the basic function of the cell membrane. **AP EK 2.B.1** goes beyond the NGSS by including details about the structural components of the cell membrane and how they contribute to the membrane's selective permeability.
2.B Growth, reproduction and dynamic homeostasis require that cells create and maintain internal environments that are different from their external environments.	**2.B.2** Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes.	**MS.LS1.A: Structure and Function** Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell. **HS.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. 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.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.	**MS-LS1-2** Develop and use a model to describe the function of a cell as a whole and ways parts of cells contribute to the function. **HS-PS3-4** 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).	The NGSS provide a foundation for **AP EK 2.B.2** by describing the basic function of the cell membrane and the transfer of energy. EK 2.B.2 goes beyond the NGSS by including details about passive and active transport.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.B Growth, reproduction and dynamic homeostasis require that cells create and maintain internal environments that are different from their external environments.	**2.B.3** Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.	**MS.LS1.A: Structure and Function** Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell.	**MS-LS1-2** Develop and use a model to describe the function of a cell as a whole and ways parts of cells contribute to the function.	The NGSS provide a foundation for **AP EK 2.B.3** by describing the basic structure and function of cell parts. EK 2.B.3 goes beyond the NGSS by including details on membrane-bound organelles that can create specialized regions.
2.C Organisms use feedback mechanisms to regulate growth and reproduction, and to maintain dynamic homeostasis.	**2.C.1** Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes.	**HS.LS1.A: Structure and Function** 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.	**HS-LS1-3** Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.	The NGSS and AP both discuss negative and positive feedback mechanisms and their role in maintaining living system conditions. **AP EK 2.C.1** goes beyond the NGSS by including details about how alterations to the feedback systems can have deleterious effects.
2.C Organisms use feedback mechanisms to regulate growth and reproduction, and to maintain dynamic homeostasis.	**2.C.2** Organisms respond to changes in their external environments.	**HS.LS1.A: Structure and Function** 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.	**HS-LS1-3** Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.	**AP EK 2.C.2** builds upon **AP EK 2.C.1** and **NGSS HS.LS1.A** by specifying how organisms use behavioral and physiological mechanisms to respond to environmental changes.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.D Growth and dynamic homeostasis of a biological system are influenced by changes in the system's environment.	**2.D.1** All biological systems from cells and organisms to populations, communities, and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy.	**HS.LS2.A: Interdependent Relationships in Ecosystems** Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. **HS.LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved. **HS.LS2.C: Ecosystem Dynamics, Functioning, and Resilience** A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability.	**HS-LS2-1** Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales. **HS-LS2-2** Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. **HS-LS2-4** Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem. **HS-LS2-6** Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.	Both AP and the NGSS describe how the stability of organisms, populations, and ecosystems can be affected by various factors. **AP EK 2.D.1** goes beyond the NGSS by including how cell activities can also be affected.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.D Growth and dynamic homeostasis of a biological system are influenced by changes in the system's environment.	**2.D.3** Biological systems are affected by disruptions to their dynamic homeostasis.	**HS.LS2.C: Ecosystem Dynamics, Functioning, and Resilience** A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. **HS.LS4.C: Adaptation** Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline–and sometimes the extinction–of some species. **HS.LS4.D: Biodiversity and Humans** Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.	**HS-LS2-6** Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. **HS-LS2-7** Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity. **HS-LS4-6** Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.*	Both the NGSS and AP include a discussion of the effect of disruptions to biological systems. The NGSS focuses on disruptions to populations and ecosystems, while **AP EK 2.D.3 part a** also includes the effects of disruptions at the molecular and cellular level.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.E Many biological processes involved in growth, reproduction and dynamic homeostasis include temporal regulation and coordination.	**2.E.1** Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms.	**HS.LS1.A: Structure and Function** 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. **HS.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.LS3.A: Inheritance of Traits** Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet known function. **HS.LS3.B: Variation of Traits** In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited. Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors.	**HS-LS1-4** Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms. **HS-LS3-1** Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring. **HS-LS3-2** Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.	The NGSS build a basic understanding of the structure and function of genes, the variation of traits, gene expression, cellular division, and cellular differentiation. This all contributes towards setting the foundation for **AP EK 2.E.1** which goes beyond the NGSS by including details about the mechanisms that regulate the normal development of organisms.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.E Many biological processes involved in growth, reproduction and dynamic homeostasis include temporal regulation and coordination.	**2.E.3** Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection.	**HS.LS2.D: Social Interactions and Group Behavior** Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives. **HS.LS4.C: Adaptation** Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline–and sometimes the extinction–of some species. Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or drastic, the opportunity for the species' evolution is lost.	**HS-LS2-8** Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce. **HS-LS4-5** Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.	AP and the NGSS both discuss how group behavior can affect the survival of species. **AP EK 2.E.3** goes beyond the NGSS by including details about innate behavior, learned behavior, and communication of and response to information in plants.
3.A Heritable information provides for continuity of life.	**3.A.1** DNA, and in some cases RNA, is the primary source of heritable information.	**HS.LS1.A: Structure and Function** Systems of specialized cells within organisms help them perform the essential functions of life. 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. **HS.LS3.A: Inheritance of Traits** Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet known function. **HS.LS3.B: Variation of Traits** In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited. Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors.	**HS-LS1-1** Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells. **HS-LS3-1** Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring. **HS-LS3-2** Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.	The NGSS and AP both describe how genetic information is stored in DNA. **AP EK 3.A.1** goes beyond the NGSS by including details about the structure and function of RNA vs. DNA, the experiments that provide evidence that DNA carries genetic information, the specific steps involved in DNA replication and protein synthesis, the difference in protein synthesis between prokaryotes and eukaryotes, the difference in genetic material between prokaryotes and eukaryotes, and genetic engineering.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.A Heritable information provides for continuity of life.	**3.A.2** In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization.	**HS.LS1.A: Structure and Function** 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. **MS.LS1.B: Growth and Development of Organisms** Organisms reproduce, either sexually or asexually, and transfer their genetic information to their offspring. **HS.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. **MS.LS3.A: Inheritance of Traits** Variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited. **HS.LS3.A: Inheritance of Traits** Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet known function. **MS.LS3.B: Variation of Traits** In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other. *(continued on next page)*	**MS-LS3-2** Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation. **HS-LS1-4** Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms. **HS-LS3-1** Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring. **HS-LS3-2** Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.	The NGSS and AP both describe the processes of mitosis and meiosis. **AP EK 3.A.2** goes beyond the NGSS by including details about the steps and regulation of the processes.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
	3.A.2 In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization.	**HS.LS3.B: Variation of Traits** In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited. Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors.		

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3.A Heritable information provides for continuity of life.	**3.A.3** The chromosomal basis of inheritance provides an understanding of the pattern of passage (transmission) of genes from parent to offspring.	**HS.LS1.A: Structure and Function** 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. **MS.LS1.B: Growth and Development of Organisms** Organisms reproduce, either sexually or asexually, and transfer their genetic information to their offspring. **MS.LS3.A: Inheritance of Traits** Variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited. **HS.LS3.A: Inheritance of Traits** Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet known function. **MS.LS3.B: Variation of Traits** In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other. **HS.LS3.B: Variation of Traits** In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited. Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors.	**MS-LS3-2** Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation. **HS-LS3-1** Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring. **HS-LS3-2** Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.	The NGSS build an understanding of the inheritance of traits and genetic variation. This contributes towards setting the foundation for **AP EK 3.A.3**, which goes beyond the NGSS by including the different patterns of inheritance; rules of probability; human genetic disorders; and ethical, medical, and social issues.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.B Expression of genetic information involves cellular and molecular mechanisms.	**3.B.1** Gene regulation results in differential gene expression, leading to cell specialization.	**HS.LS1.A: Structure and Function** 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. **HS.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.LS3.A: Inheritance of Traits** Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet known function.	**HS-LS1-4** Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms. **HS-LS3-1** Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.	The NGSS introduce the concept of gene regulation. **AP EK 3.B.1** goes beyond the NGSS by describing how genes are regulated in eukaryotes and the specific control mechanisms that are present for gene regulation in bacteria and viruses.
3.B Expression of genetic information involves cellular and molecular mechanisms.	**3.B.2** A variety of intercellular and intracellular signal transmissions mediate gene expression.	**HS.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** Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.	**NGSS HS.LS1.B** builds an understanding of cell division and differentiation that sets a foundation for **AP EK 3.B.2.** EK 3.B.2 includes details about intercellular and intracellular signal transmissions that are involved with gene expression.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.C The processing of genetic information is imperfect and a source of genetic variation.	**3.C.1** Changes in genotype can result in changes in phenotype.	**MS.LS3.A: Inheritance of Traits** Genes are located in the chromosomes of cells, with each chromosome pair containing two variants of each of many distinct genes. Each distinct gene chiefly controls the production of specific proteins, which in turn affects the traits of the individual. Changes (mutations) to genes can result in changes to proteins, which can affect the structures and functions of the organism and thereby change traits. **MS.LS3.B: Variation of Traits** In addition to variations that arise from sexual reproduction, genetic information can be altered because of mutations. Though rare, mutations may result in changes to the structure and function of proteins. Some changes are beneficial, others harmful, and some neutral to the organism. **HS.LS3.B: Variation of Traits** In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited. Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors. **LS4.B: Natural Selection** Natural selection occurs only if there is both (1) variation in the genetic information between organisms in a population and (2) variation in the expression of that genetic information—that is, trait variation—that leads to differences in performance among individuals. The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population. **LS4.C: Adaptation** Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not. Adaptation also means that the distribution of traits in a population can change when conditions change.	**MS-LS3-1** Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism. **HS-LS3-2** Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors. **HS-LS4-3** Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.	Both the NGSS and AP describe how changes in a gene can affect traits, and that the changes in the genes are subject to natural selection. **AP EK 3.C.1** specifically uses the terms genotype and phenotype in this discussion. AP EK 3.C.1 goes beyond the NGSS by including details about how mutations can arise other than during errors in DNA replication, and how errors during mitosis and meiosis can result in changes in chromosome numbers.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.C The processing of genetic information is imperfect and a source of genetic variation.	**3.C.2** Biological systems have multiple processes that increase genetic variation.	**HS.LS3.B: Variation of Traits** In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited. Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors.	**HS-LS3-2** Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.	The NGSS and AP both describe how errors during DNA replication and crossing-over during meiosis can contribute towards genetic variation and how the resulting traits are subject to natural selection. **AP EK 3.C.1** goes beyond the NGSS by including details about the processes that increase genetic variation in prokaryotes.
3.D Cells communicate by generating, transmitting and receiving chemical signals.	**3.D.2** Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling.	**MS.LS1.D: Information Processing** Each sense receptor responds to different inputs (electromagnetic, mechanical, chemical), transmitting them as signals that travel along nerve cells to the brain. The signals are then processed in the brain, resulting in immediate behaviors or memories.	**MS-LS1-8** Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories.	Both the NGSS and AP describe how information is transmitted via nerve cells. **AP EK 3.D.2** differentiates between the different ways that cells can communicate: cell-to-cell contact, short distance signaling, and long distance signaling.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.E Transmission of information results in changes within and between biological systems.	**3.E.1** Individuals can act on information and communicate it to others.	**HS.LS2.D: Social Interactions and Group Behavior** Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives. **HS.LS4.B: Natural Selection** Natural selection occurs only if there is both (1) variation in the genetic information between organisms in a population and (2) variation in the expression of that genetic information—that is, trait variation—that leads to differences in performance among individuals. The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population. **HS.LS4.C: Adaptation** Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not. Adaptation also means that the distribution of traits in a population can change when conditions change.	**HS-LS2-8** Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce. **HS-LS4-3** Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.	Both the NGSS and AP describe how natural selection favors behavior that increases survival. **AP EK 3.E.1** goes beyond the NGSS by include details about how communication between organisms can change behavior and about communication mechanisms. It also separates behavior into learned and innate behavior in **part c.1**.
3.E Transmission of information results in changes within and between biological systems.	**3.E.2** Animals have nervous systems that detect external and internal signals, transmit and integrate information, and produce responses.	**HS.LS1.A: Structure and Function** Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. **MS.LS1.D: Information Processing** Each sense receptor responds to different inputs (electromagnetic, mechanical, chemical), transmitting them as signals that travel along nerve cells to the brain. The signals are then processed in the brain, resulting in immediate behaviors or memories. **HS.PS3.C: Relationship Between Energy and Forces** When two objects interacting through a field change relative position, the energy stored in the field is changed.	**MS-LS1-8** Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories. **HS-LS1-2** Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms. **HS-PS3-5** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	The NGSS set the foundation for **AP EK 3.E.2** by describing how information is processed through nerve cells, how components interact within systems, and how energy can be stored in fields. AP EK 3.E.2 goes beyond the NGSS by including the structure of a neuron, the propagation of impulses, steps involved in transmitting information across synapses, and the different functions of brain regions.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.A Interactions within biological systems lead to complex properties.	**4.A.1** The subcomponents of biological molecules and their sequence determine the properties of that molecule.	**HS.LS1.A: Structure and Function** Systems of specialized cells within organisms help them perform the essential functions of life. 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. **HS.LS1.C: Organization for Matter and Energy Flow in Organisms** 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. As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. **HS.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.	**HS-LS1-1** Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells. **HS-LS1-6** 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. **HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.	The NGSS describe how the parts of a molecule determine its properties. **NGSS HS.LS1.C** includes details for the structure of carbohydrates and **NGSS HS.PS2.B** discusses the contribution of attraction and repulsion towards a molecule's properties. **AP EK 4.A.1** goes beyond the NGSS by including details about the structure and properties of nucleic acids (**part a.1**), proteins (**part a.2**) and lipids (**part a.3**). EK 4.A.1 also includes details about how the directionality of components can affect structure and function of the molecule.
4.A Interactions within biological systems lead to complex properties.	**4.A.2** The structure and function of subcellular components, and their interactions, provide essential cellular processes.	**MS.LS1.A: Structure and Function** Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell. **HS.LS1.C: Organization for Matter and Energy Flow in Organisms** The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.	**MS-LS1-2** Develop and use a model to describe the function of a cell as a whole and ways parts of cells contribute to the function. **HS-LS1-5** Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.	Both the NGSS and AP discuss how subcellular components have specific structures and functions. **NGSS HS.LS.1.A** specifically mentions the cell membrane and **HS.LS1.C** builds a foundation for understanding the structure and function of a chloroplast. **AP EK 4.A.2** includes details about the structure and function of the endoplasmic reticulum, ribosomes, the golgi complex, mitochondria, lysosomes, vacuoles, and chloroplasts.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.A Interactions within biological systems lead to complex properties.	**4.A.3** Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues and organs.	**HS.LS1.A: Structure and Function** Systems of specialized cells within organisms help them perform the essential functions of life. 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. Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. **HS.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.LS3.A: Inheritance of Traits** Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet known function. **HS.LS3.B: Variation of Traits** Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors.	**HS-LS1-1** Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells. **HS-LS1-2** Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms. **HS-LS1-4** Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms. **HS-LS3-1** Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring. **HS-LS3-3** Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.	AP and NGSS both describe that genes are regulated, how the environment can affect gene expression, and how differentiation results in specialized tissues and organs. **AP EK 4.A.3** goes beyond the NGSS by including details about the cues for gene regulation, regulation by proteins, and how this regulation leads to differentiation. The NGSS build the foundation for EK 4.A.3 by describing what genes are and how cell division and differentiation contribute towards the growth and development of an organism.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.A Interactions within biological systems lead to complex properties.	**4.A.4** Organisms exhibit complex properties due to interactions between their constituent parts.	**HS.LS1.A: Structure and Function** Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level.	**HS-LS1-2** Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.	Both the NGSS and AP discuss how the interactions between different systems and between components of a single system contribute towards the functioning of organisms. **AP EK 4.A.4** specifically differentiates between interactions at the organ level and interactions at the system level.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.A Interactions within biological systems lead to complex properties.	**4.A.5** Communities are composed of populations of organisms that interact in complex ways.	**MS.LS2.A: Interdependent Relationships in Ecosystems** Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared. **HS.LS2.A: Interdependent Relationships in Ecosystems** Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. **HS.LS2.C: Ecosystem Dynamics, Functioning, and Resilience** A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. **HS.LS4.C: Adaptation** Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline–and sometimes the extinction–of some species. **HS.LS4.D: Biodiversity and Humans** Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). *(continued on next page)*	**MS-LS2-2** Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems. **HS-LS2-1** Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales. **HS-LS2-2** Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. **HS-LS2-6** Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. **HS-LS2-7** Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity. **HS-LS4-6** Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.* **HS-ESS3-5** Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems. *(continued on next page)*	The NGSS build a foundation for **AP 4.A.5** by describing how populations interact, and the use of mathematical models and representations to explain and illustrate both these interactions as well as the factors that affect the interactions. EK 4.A.5 goes beyond the NGSS by including how community structure can be described by species composition and diversity, exponential growth, logistic growth, density-dependent and density-independent factors, and demographics data (for use in human population studies).

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
	4.A.5 Communities are composed of populations of organisms that interact in complex ways.	Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. **HS.ESS2.D: Weather and Climate** Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere. **HS.ESS3.D: Global Climate Change** Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts. Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.	**HS-ESS3-6** Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.	

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.A Interactions within biological systems lead to complex properties.	**4.A.6** Interactions among living systems and with their environment result in the movement of matter and energy.	**HS.LS2.A: Interdependent Relationships in Ecosystems** Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. **HS.LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved. **HS.LS2.C: Ecosystem Dynamics, Functioning, and Resilience** Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. **HS.LS4.D: Biodiversity and Humans** Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. *(continued on next page)*	**HS-LS2-1** Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales. **HS-LS2-2** Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. **HS-LS2-4** Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem. **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. **HS-LS2-7** Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.* **HS-LS4-6** Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.* **HS-ESS3-6** Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.	The NGSS and AP both describe how interactions in food webs and chains move matter and energy. **NGSS HS.LS2.A** and **HS.LS2.C** build a foundation for **AP EK 4.A.6** by describing the dynamics and relationships in ecosystems. EK 4.A.6 includes details about how changes in ecosystems can affect primary productivity and how competition contributes to logistic model growth and a density-dependent population. **NGSS HS.LS2.C, NGSS HS.LS4.D**, and **EK 4.A.6 part f** describe how human activities impact ecosystems, but EK 4.A.6 part f separates human impact into local, regional, and global scales.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
	4.A.6 Interactions among living systems and with their environment result in the movement of matter and energy.	Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). **HS.PS3.D: Energy in Chemical Processes** The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. **HS.ESS2.D: Weather and Climate** Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere. **HS.ESS3.D: Global Climate Change** Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.		

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.B Competition and cooperation are important aspects of biological systems.	**4.B.1** Interactions between molecules affect their structure and function.	**HS.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.	**HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.	**NGSS HS.PS2.B** builds a foundation for **AP EK 4.B.1** by describing how attraction and repulsion between charges contributes towards the structure and function of molecules. EK 4.B.1 specifically discusses how the structure of an enzyme determines its function, the binding of molecules to enzymes, and how changes in structure can result changes in function.
4.B Competition and cooperation are important aspects of biological systems.	**4.B.2** Cooperative interactions within organisms promote efficiency in the use of energy and matter.	**MS.LS1.A: Structure and Function** Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell. **HS.LS1.A: Structure and Function** Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. Systems of specialized cells within organisms help them perform the essential functions of life. 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.	**MS-LS1-2** Develop and use a model to describe the function of a cell as a whole and ways parts of cells contribute to the function. **HS-LS1-1** Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells. **HS-LS1-2** Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms	**NGSS MS.LS1.A** and **HS.LS1.A** describe the hierarchy of living systems, the components of the different levels, and the interactions within and between each level, leading students to an understanding in **AP EK 4.B.2** of how components at the different levels within an organism have functions involving the use of energy and matter. **EK 4.B.2 part 3** also goes beyond the NGSS by specifically including details about interactions between unicellular organisms.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.B Competition and cooperation are important aspects of biological systems.	**4.B.3** Interactions between and within populations influence patterns of species distribution and abundance.	**MS.LS2.A Interdependent Relationships in Ecosystems** Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared. **HS.LS2.A Interdependent Relationships in Ecosystems** Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. **HS.LS2.C Ecosystem Dynamics, Functioning, and Resilience** Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. **HS.LS2.D Social Interactions and Group Behavior** Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives. **HS.LS4.C Adaptation** Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline–and sometimes the extinction–of some species. *(continued on next page)*	**MS-LS2-2** Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems. **HS-LS2-2** Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. **HS-LS2-6** Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. **HS-LS2-7** Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.* **HS-LS2-8** Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce. **HS-LS4-6** Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.*	Both the NGSS and AP describe how interactions between populations can affect their numbers and how environmental disturbances (human impacts included) can also affect population numbers. **AP EK 4.B.3** goes beyond the NGSS by describing how the properties of a population are different than the properties of the individuals.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
	4.B.3 Interactions between and within populations influence patterns of species distribution and abundance.	**HS.LS4.D Biodiversity and Humans** Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.		
4.B Competition and cooperation are important aspects of biological systems.	**4.B.4** Distribution of local and global ecosystems changes over time.	**HS.LS2.C Ecosystem Dynamics, Functioning, and Resilience** Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. **HS.LS4.C Adaptation** Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline–and sometimes the extinction–of some species. **HS.LS4.D Biodiversity and Humans** Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. **HS.ESS2.A Earth Materials and Systems** Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. *(continued on next page)*	**HS-LS2-7** Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.* **HS-LS4-6** Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.* **HS-ESS2-2** Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems. **HS-ESS3-1** Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. **HS-ESS3-6** Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.	Both AP and the NGSS describe how natural events and human activities impact ecosystems.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
	4.B.4 Distribution of local and global ecosystems changes over time.	**HS.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. Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere. **HS.ESS3.A Natural Resources** Resource availability has guided the development of human society. **HS.ESS3.B Natural Hazards** Natural hazards and other geologic events have shaped the course of human history; [they] have significantly altered the sizes of human populations and have driven human migrations. **HS.ESS3.D Global Climate Change** Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.		
4.C Naturally occurring diversity among and between components within biological systems affects interactions with the environment.	**4.C.1** Variation in molecular unites provides cells with a wider range of functions.	**MS.LS1.B Growth and Development of Organisms** Organisms reproduce, either sexually or asexually, and transfer their genetic information to their offspring. **HS.LS3.A Inheritance of Traits** Variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited. **HS.LS3.B Variation of Traits** In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other.	**MS-LS3-2** Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation.	The NGSS build the foundational knowledge needed for **AP EK 4.C.1**, including the transfer of genetic information and the variation of inherited traits. EK 4.C.1 goes beyond the NGSS by describing how variation in molecular classes and gene duplication can result in more functions and phenotypes.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.C Naturally occurring diversity among and between components within biological systems affects interactions with the environment.	**4.C.2** Environmental factors influence the expression of the genotype in an organism.	**HS.LS3.B Variation of Traits** Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors.	**HS-LS3-3** Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.	Both the NGSS and AP include how environmental factors affect the expression of traits. **AP EK 4.C.2 part b** goes beyond the NGSS by including how "an organism's adaptation to the local environment reflects a flexible response of its genome."
4.C Naturally occurring diversity among and between components within biological systems affects interactions with the environment.	**4.C.3** The level of variation in a population affects population dynamics.	**HS.LS3.B Variation of Traits** Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors. **HS.LS4.C Adaptation** Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline–and sometimes the extinction–of some species. Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or drastic, the opportunity for the species' evolution is lost.	**HS-LS3-3** Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population. **HS-LS4-5** Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.	The NGSS build a foundation for **AP EK 4.C.3** by describing adaptation and how environmental factors affect gene expression. EK 4.C.3 goes beyond the NGSS by including details about genetic diversity and its contribution toward an organism or population's ability to respond. **EK 4.C.3 part c** also includes the Hardy-Weinberg equation.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.C Naturally occurring diversity among and between components within biological systems affects interactions with the environment.	**4.C.4** The diversity of species within an ecosystem may influence the stability of the ecosystem.	**HS.LS2.A Interdependent Relationships in Ecosystems** Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. **HS.LS2.C Ecosystem Dynamics, Functioning, and Resilience** A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. **HS.LS4.C Adaptation** Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline–and sometimes the extinction–of some species. Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or drastic, the opportunity for the species' evolution is lost.	**HS-LS2-2** Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. **HS-LS4-5** Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.	The NGSS build a foundation for **AP EK 4.C.4** by describing how disturbances to ecosystems can result in resilience or change. EK 4.C.4 goes beyond the NGSS by including details about how the diversity of the components of an ecosystem contributes towards its resilience. **EK 4.C.4 part b** goes beyond the NGSS by describing keystone species and their contribution towards the diversity of ecosystems.

APPENDIX B
NGSS & AP Chemistry Comparison Chart

What was evaluated and compared?

- For this comparison, the specific language of each AP Essential Knowledge (AP EK) statement was compared to the Disciplinary Core Idea (DCI) elements associated with each Next Generation Science Standards (NGSS) Performance Expectation (PE) to determine whether the two share a similar content or conceptual foundation.
- The NGSS and the AP course guides are very different in intended format, audience (the NGSS is for all students whereas the AP course guides cover college-level content), and content emphasis, particularly the emphasis in the NGSS on all three components of the foundation boxes. Therefore, this document focuses solely on the overlap of disciplinary content rather than on any similarities related to the practices or crosscutting concepts. When comparing the AP EK content to the NGSS, only the DCI elements associated with each PE were used in the comparison. This is not to be taken as a devaluation of the practices or crosscutting concepts. A discussion of practices and crosscutting concepts can be found on page 23.

How is the chart organized?

- The charts are organized by the AP EK statements and include some possible DCI elements that overlap with or build a foundation for the AP content in each EK statement. AP EK statements are not included in the course chart if no similarity was found between them and the NGSS content.
- The entirety of the EK text is not included in each row. Most EK statements have a general statement and then multiple supporting parts for the statement. While all parts of the EK text were evaluated for the comparison, the chart only includes the general EK statement. Where appropriate, the comments in each row refer to individual parts of the EK text. For the full EK text, please see the AP Chemistry Course and Exam Description from College Board.
- The full text for each identified DCI is not included in the chart. Only the DCI elements that overlap with or provide a foundation for the AP EK statements are included in the chart.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.A All matter is made of atoms. There are a limited number of types of atoms; these are the elements.	**1.A.1** Molecules are composed of specific combinations of atoms; different molecules are composed of combinations of different elements and of combinations of the same elements in differing amounts and proportions.	**MS.PS1.A: Structure and Properties of Matter** Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals).	**MS-PS1-1** Develop models to describe the atomic composition of simple molecules and extended structures.	Both **NGSS MS.PS1.A** and **AP EK 1.A.1** describe the basic composition of molecules. However, **EK 1.A.1 parts a through d** include details (e.g., about atomic mass) that are not included in the NGSS.
1.A All matter is made of atoms. There are a limited number of types of atoms; these are the elements.	**1.A.3** The mole is the fundamental unit for counting numbers of particles on the macroscopic level and allows quantitative connections to be drawn between laboratory experiments, which occur at the macroscopic level, and chemical processes, which occur at the atomic level.	**HS.PS1.B: Chemical Reactions** 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. 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-PS1-6** Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium. **HS-PS1-7** Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.	Both **NGSS HS.PS1.B** and **AP EK1.A.3** describe balanced chemical equations and the idea of quantifying numbers of atoms. **NGSS PE HS-PS1-7** makes this connection even more clear through its integration of the practice with the DCI and crosscutting concept. EK 1.A.3, however, includes details of the mole and Avogadro's number that are not included in the NGSS.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.B The atoms of each element have unique structures arising from interactions between electrons and nuclei.	**1.B.1** The atom is composed of negatively charged electrons, which can leave the atom, and a positively charged nucleus that is made of protons and neutrons. The attraction of the electrons to the nucleus is the basis of the structure of the atom. Coulomb's law is qualitatively useful for understanding the structure of the atom.	**HS.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. 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.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. 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.	**HS-PS1-1** 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. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.	The NGSS and AP both describe the attraction between charged particles as a key component to the structure and properties of the atom. **AP EK 1.B.1 parts a through c** include details of Coulomb's law and ionization energy that are not specified in the NGSS. **EK 1.B.1 parts d and e** also relate to **NGSS HS.PS4.B**, but the AP parts include more detail about Photoelectron spectroscopy than does the NGSS.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.B The atoms of each element have unique structures arising from interactions between electrons and nuclei.	**1.B.2** The electronic structure of the atom can be described using an electron configuration that reflects the concept of electrons in quantized energy levels or shells; the energetics of the electrons in the atom can be understood by consideration of Coulomb's law.	**HS.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. 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.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.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. 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.	**HS-PS1-1** 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. **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. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.	The NGSS and AP both describe the energetics of electrons in atoms as being described by Coulomb's law. The NGSS, however, only focus on the outer electrons of atoms, whereas **AP EK 1.B.2** describes the different energy levels or "shells" of electrons.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.C Elements display periodicity in their properties when the elements are organized according to increasing atomic number. This periodicity can be explained by the regular variations that occur in the electronic structures of atoms. Periodicity is a useful principle of understanding properties and predicting trends in properties. Its modern-day uses range from examining the composition of materials to generating ideas for designing new materials.	**1.C.1** Many properties of atoms exhibit periodic trends that are reflective of the periodicity of electronic structure.	**HS.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. 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.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.	**HS-PS1-1** 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.	Both **NGSS HS.PS1.A** and **AP EK 1.C.1** describe periodicity of the elements. EK 1.C.1 includes additional details about electron shells, ionization energy, and atomic radii that are not included in the NGSS.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.C Elements display periodicity in their properties when the elements are organized according to increasing atomic number. This periodicity can be explained by the regular variations that occur in the electronic structures of atoms. Periodicity is a useful principle of understanding properties and predicting trends in properties. Its modern-day uses range from examining the composition of materials to generating ideas for designing new materials.	**1.C.2** The currently accepted best model of the atom is based on the quantum mechanical model.	**HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.	**HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.	**NGSS HS.PS2.B** forms a foundation for **AP EK 1.C.2** by describing Coulomb's law in reference to subatomic particles. EK 1.C.2 goes beyond the NGSS, however, by describing the quantum mechanical model of the atom, including electron spin.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.D Atoms are so small that they are difficult to study directly; atomic models are constructed to explain experimental data on collections of atoms.	**1.D.1** As is the case with all scientific models, any model of the atom is subject to refinement and change in response to new experimental results. In that sense, an atomic model is not regarded as an exact description of the atom, but rather a theoretical construct that fits a set of experimental data.	**HS.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. 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. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. **HS.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.	**HS-PS1-1** 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. **HS-PS1-3** 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	The NGSS form the foundation for **AP EK 1.D.1** by describing a basic model of the atom in **NGSS HS.PS1.A** and by describing electrical forces within atoms in both **HS.PS1.A** and **HS.PS2.B**, leading students to an understanding of ionization energies for **EK 1.D.1 part b**.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.D Atoms are so small that they are difficult to study directly; atomic models are constructed to explain experimental data on collections of atom.	**1.D.3** The interaction of electromagnetic waves or light with matter is a powerful means to probe the structure of atoms and molecules, and to measure their concentration.	**HS.PS3.C: Relationship Between Energy and Forces** When two objects interacting through a field change relative position, the energy stored in the field is changed. **HS.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. Photoelectric materials emit electrons when they absorb light of a high-enough frequency. **HS.PS4.C: Information Technologies and Instrumentation** Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them. **HS.ESS1.A: The Universe and Its Stars** 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.	**HS-PS3-5** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. **HS-PS4-5** Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. **HS-ESS1-2** 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.	Both the NGSS and **AP EK 1.D.3** describe interactions of electromagnetic waves (or light) with matter, and that information can be gained through this interaction. **EK 1.D.3 part a** goes beyond the NGSS by describing Planck's equation. **EK 1.D.3 part b** describes some specific uses of infrared vs. ultraviolet and visible radiation, which also relates to other parts of **NGSS HS.PS4.B** that are not included here (associated with **HS-PS4-4**). **EK 1.D.3 part c** goes beyond the NGSS by describing use of the Beer-Lambert law.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.E Atoms are conserved in physical and chemical processes.	**1.E.1** Physical and chemical processes can be depicted symbolically; when this is done, the illustration must conserve all atoms of all types.	**HS.PS1.A: Structure and Properties of Matter** 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.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.PS3.D: Energy in Chemical Processes** The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. **HS.ESS2.D: Weather and Climate** 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. **HS.LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved. Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.	**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. **HS-PS1-7** Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. **HS-ESS2-6** Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere. **HS-LS2-4** Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem. **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.	Both the NGSS and **AP EK 1.E.1** describe that atoms are conserved during chemical reactions and that these reactions can be depicted symbolically. **EK 1.E.1 part a** goes beyond the NGSS by describing two specific different types of representations of physical and chemical processes.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.E Atoms are conserved in physical and chemical processes.	**1.E.2** Conservation of atoms makes it possible to compute the masses of substances involved in physical and chemical processes. Chemical processes result in the formation of new substances, and the amount of these depends on the number and the types and masses of elements in the reactants, as well as the efficiency of the transformation.	**HS.PS1.A: Structure and Properties of Matter** 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.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** 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. **HS-PS1-7** Use mathematical representations to support the claim that atoms, and therefore mass, are conserved	Both the NGSS and **AP EK 1.E.2** connect conservation of atoms to quantification of chemical reactants and products. EK 1.E.2 goes beyond the NGSS by describing gravimetric analysis and titrations in **parts e and f**.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.A Matter can be described by its physical properties. The physical properties of a substance generally depend on the spacing between the particles (atoms, molecules, ions) that make up the substance and the forces of attraction among them.	**2.A.1** The difference properties of solids and liquids can be explained by differences in their structures, both at the particulate level and in their supramolecular structures.	**MS.PS1.A: Structure and Properties of Matter** Gases and liquids are made of molecules or inert atoms that are moving about relative to each other. In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations. The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter. **MS.PS3.A: Definitions of Energy** The term "heat as used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and the transfer of that thermal energy from one object to another. In science, heat is used only for this second meaning; it refers to the energy transferred due to the temperature difference between two objects. The temperature of a system is proportional to the average kinetic energy and potential energy per atom or molecule (whichever is the appropriate building block for the system's material). The details of that relationship depend on the type of atom or molecule and the interactions among the atoms in the material. Temperature is not a direct measure of a system's total thermal energy. The total thermal energy (sometimes called the total internal energy) of a system depends jointly on the temperature, the total number of atoms in the system, and the state of the material. **HS.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. 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. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. **HS.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. *(continued on next page)*	**MS-PS1-4** Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed. **HS-PS1-1** 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. **HS-PS1-3** 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. **HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).	Both the NGSS and **AP EK 2.A.1** describe the differences between solids and liquids at a molecular level, and describe strength of attraction between particles as an explanation for the properties of matter. The NGSS build the foundation for discussion of different states of matter in middle school. **EK 2.A.1 part a** also relates to other parts of **MS.PS1.A** that are not listed here (regarding crystal structures). **EK 2.A.1 part e** goes beyond the NGSS by describing energetics of liquid/solid phase changes.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
	2.A.1 The difference properties of solids and liquids can be explained by differences in their structures, both at the particulate level and in their supramolecular structures.	**HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.		
2.A Matter can be described by its physical properties. The physical properties of a substance generally depend on the spacing between the particles (atoms, molecules, ions) that make up the substance and the forces of attraction among them.	**2.A.2** The gaseous state can be effectively modeled with a mathematical equation relating various macroscopic properties. A gas has neither a definite volume nor a definite shape; because the effects of attractive forces are minimal, we usually assume that the particles move independently.	**MS.PS1.A: Structure and Properties of Matter** Gases and liquids are made of molecules or inert atoms that are moving about relative to each other. In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations. The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter. **MS.PS3.A: Definitions of Energy** The term "heat as used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and the transfer of that thermal energy from one object to another. In science, heat is used only for this second meaning; it refers to the energy transferred due to the temperature difference between two objects. *(continued on next page)*	**MS-PS1-4** Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed. **HS-PS1-3** 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. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. *(continued on next page)*	Both the NGSS and **AP EK 2.A.2** describe gases and the intermolecular interactions that govern the behavior of gases. The NGSS build the foundation for discussion of different states of matter in middle school, and then build the foundation for mathematical representations of gas laws through a thorough coverage of intermolecular forces and energy in the high school standards. EK 2.A.2 goes beyond the NGSS by describing ideal gases; by describing the mathematical relationships between P, V, and T; and by discussing qualitative use of the Maxwell-Boltzmann distribution.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
	2.A.2 The gaseous state can be effectively modeled with a mathematical equation relating various macroscopic properties. A gas has neither a definite volume nor a definite shape; because the effects of attractive forces are minimal, we usually assume that the particles move independently.	The temperature of a system is proportional to the average kinetic energy and potential energy per atom or molecule (whichever is the appropriate building block for the system's material). The details of that relationship depend on the type of atom or molecule and the interactions among the atoms in the material. Temperature is not a direct measure of a system's total thermal energy. The total thermal energy (sometimes called the total internal energy) of a system depends jointly on the temperature, the total number of atoms in the system, and the state of the material. **HS.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. 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. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. **HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. 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. **HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. *(continued on next page)*	**HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.* **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). **HS-PS3-4** 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). **HS-PS3-5** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
	2.A.2 The gaseous state can be effectively modeled with a mathematical equation relating various macroscopic properties. A gas has neither a definite volume nor a definite shape; because the effects of attractive forces are minimal, we usually assume that the particles move independently.	These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. **HS.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. 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.C: Relationship Between Energy and Forces** When two objects interacting through a field change relative position, the energy stored in the field is changed. **HS.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.		
2.A Matter can be described by its physical properties. The physical properties of a substance generally depend on the spacing between the particles (atoms, molecules, ions) that make up the substance and the forces of attraction among them.	**2.A.3** Solutions are homogenous mixtures in which the physical properties are dependent on the concentration of the solute and the strengths of all interactions among the particles of the solutes and solvent.	**HS.PS1.A: Structure and Properties of Matter** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. 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.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.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.	**HS-PS1-4** 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. **HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*	The NGSS build the foundation for **AP EK 2.A.3** by describing release or absorption of energy during reactions, and by describing intermolecular interactions. EK 2.A.3 goes beyond the NGSS by including details of solutions, their properties, how to describe solutions with molarity, and by descriptions of distillation.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.B Forces of attraction between particles (including the noble gases and also different parts of some large molecules) are important in determining many macroscopic properties of a substance, including how the observable physical state changes with temperature.	**2.B.3** Intermolecular forces place a key role in determining the properties of substances, including biological structures and interactions.	**HS.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. 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. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. **HS.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. **HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.	**HS-PS1-1** 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. **HS-PS1-3** 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. **HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.* **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).	The NGSS and **AP EK 2.B.3** both describe intermolecular forces as crucial to determining the properties of substances. EK 2.B.3 goes beyond the NGSS by describing some effects of intermolecular forces on gases, including noble gases (**part c**), discussing graphs of pressure-volume relationships (**part d**), and by including examples of enzyme catalysis and hydrophilic and hydrophobic regions of proteins (**part e**).

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.C The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.	**2.C.1** In covalent bonding, electrons are shared between the nuclei of two atoms to form a molecule or polyatomic ion. Electronegativity differences between the two atoms account for the distribution of the shared electrons and the polarity of the bond.	**HS.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 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. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. 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.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. 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.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. 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. *(continued on next page)*	**HS-PS1-1** 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. **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. **HS-PS1-3** 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. **HS-PS1-4** 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. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). *(continued on next page)*	Bonding is a result of forces, proximity, and energy. This provides a basis for understanding all types of bonding. Both the NGSS and **AP EK 2.C.1** describe bonding as a result of intermolecular forces, and both describe bond energies. EK 2.C.1 goes beyond the NGSS by describing specific types of bonds (e.g., polar covalent, nonpolar covalent, ionic) and bond lengths.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
	2.C.1 In covalent bonding, electrons are shared between the nuclei of two atoms to form a molecule or polyatomic ion. Electronegativity differences between the two atoms account for the distribution of the shared electrons and the polarity of the bond.	**HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. **HS.PS3.C: Relationship Between Energy and Forces** When two objects interacting through a field change relative position, the energy stored in the field is changed.	**HS-PS3-5** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.C The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.	**2.C.2** Iconic bonding results from the net attraction between oppositely charged ions, closely packed together in a crystal lattice.	**HS.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. 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. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. 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.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.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. 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. **HS.PS3.C: Relationship Between Energy and Forces** When two objects interacting through a field change relative position, the energy stored in the field is changed.	**HS-PS1-1** 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. **HS-PS1-3** 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. **HS-PS1-4** 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. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. **HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.* **HS-PS3-5** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	Bonding is a result of forces, proximity, and energy. This provides a basis for understanding all types of bonding. Both the NGSS and **AP EK 2.C.2** describe intermolecular forces and Coulomb's law as describing electrostatic forces between particles. EK 2.C.2 goes beyond the NGSS by describing cations and anions in an ionic crystal lattice.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.C The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.	**2.C.3** Metallic bonding describes an array of positively charged metal cores surrounded by sea of mobile valence electrons.	**HS.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. 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.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. 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.	**HS-PS1-1** 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. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.	Bonding is a result of forces, proximity, and energy. This provides a basis for understanding all types of bonding. Both the NGSS and **AP EK 2.C.3** describe valence electrons relating to the patterns of properties of materials, and describe attraction between particles. EK 2.C.3 goes beyond the NGSS by relating these concepts to a description of metallic bonding.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.D The type of bonding in the solid state can be deduced from the properties of the solid state.	**2.D.1** Iconic solids have high melting points, are brittle, and conduct electricity only when molten or in solution.	**HS.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. 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. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. **HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. 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.	**HS-PS1-1** 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. **HS-PS1-3** 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. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. **HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*	Both the NGSS and **AP EK 2.D.1** describe Coulombic interactions between particles and their effects on the properties of materials. EK 2.D.1 goes beyond the NGSS, however, by including details of ionic solids and their specific properties.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.D The type of bonding in the solid state can be deduced from the properties of the solid state.	**2.D.2** Metallic solids are good conductors of heat and electricity, have a wide range of melting points, and are shiny malleable, ductile, and readily alloyed.	**HS.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. 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. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. **HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. 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.	**HS-PS1-1** 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. **HS-PS1-3** 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. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. **HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*	Both the NGSS and **AP EK 2.D.2** describe valence electrons relating to the patterns of properties of materials. EK 2.D.2 goes beyond the NGSS by including details of properties of metals and alloys.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.D The type of bonding in the solid state can be deduced from the properties of the solid state.	**2.D.3** Covalent network solids have properties that reflect their underlying 2-D or 3-D networks of covalent bonds. Covalent network solids generally have extremely high melting points and are hard.	**HS.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. 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. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. **HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. 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.	**HS-PS1-1** 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. **HS-PS1-3** 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. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. **HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*	Both the NGSS and **AP EK 2.D.3** describe intermolecular forces and periodicity relating to the patterns of properties of materials. EK 2.D.3 goes beyond the NGSS by including details and properties of covalent network solids and of Graphite and Silicon.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.D The type of bonding in the solid state can be deduced from the properties of the solid state.	**2.D.4** Molecular solids with low molecular weight usually have low melting points and are not expected to conduct electricity as solids, in solution, or when molten.	**HS.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. 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. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. **HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. 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.	**HS-PS1-1** 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. **HS-PS1-3** 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. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. **HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*	Both the NGSS and **AP EK 2.D.4** describe intermolecular forces relating to the patterns of properties of materials. EK 2.D.4 goes beyond the NGSS by including molecular solids and their properties.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.A Chemical changes are represented by a balanced chemical equation that identifies the ratios with which reactants react and products form.	**3.A.1** A chemical change may be represented by a molecular, iconic, or net iconic equation.	**HS.PS1.B: Chemical Reactions** 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. 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-PS1-6** Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium. **HS-PS1-7** Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.	The NGSS provide a foundation for **AP EK 3.A.1** by describing symbolic representations of balanced chemical equations, and by emphasizing conservation of atoms in chemical reactions. However, EK 3.A.1 is more specific than the NGSS. In particular, **EK 3.A.1 part b** goes beyond the NGSS by differentiating between molecular, ionic, and net ionic reaction equations and the situations in which they might be used.
3.A Chemical changes are represented by a balanced chemical equation that identifies the ratios with which reactants react and products form.	**3.A.2** Quantitative information can be derived from stoichiometric calculations that utilize the mole ratios from the balanced chemical equations. The role of stoichiometry in real-world applications is important to note, so that it does not seem to be simply an exercise done only by chemists.	**HS.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-PS1-7** Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.	**NGSS HS.PS1.B** provides a foundation for **AP EK 3.A.2** by describing conservation of atoms and symbolic representations of chemical reactions. EK 3.A.2 goes beyond the NGSS by discussing mole ratios, requiring calculations of chemical products (**part a**), and by discussing the use of solution chemistry and titrations as avenues for calculations of stoichiometry (**part c**). This EK also relates to other parts of HS.PS1.B not listed here (e.g., associated with **HS-PS1-6**).

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.B Chemical reactions can be classified by considering what the reactants are, what the products are, or how they changed from one into the other. Classes of chemical reaction include synthesis, decomposition, acid-base, and oxidation-reduction reactions.	**3.B.1** Synthesis reactions are those in which atoms and/or molecules combine to form a new compound. Decomposition is the reverse of synthesis, a process whereby molecules are decomposed, often by the use of heat.	**HS.PS1.A: Structure and Properties of Matter** 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.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** 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 NGSS provide a foundation for **AP EK 3.B.1** by describing the outcomes of simple chemical reactions. EK 3.B.1 goes beyond the NGSS by explicitly naming synthesis and decomposition reactions. This EK also relates to other parts of **NGSS HS.PS1.A** not listed here (e.g., associated with **HS-PS1-4**).

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.C Chemical and physical transformations may be observed in several ways and typically involve a change in energy.	**3.C.1** Production of heat or light, formation of a gas, and formation of a precipitate and/or a color change are possible evidences that a chemical change has occurred.	**HS.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. 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. 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.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. 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.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.	**HS-PS1-1** 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. **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. **HS-PS1-4** 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.	The NGSS and **AP EK 3.C.1** both describe the connection between molecular structure and macroscopic properties, that changes in properties can occur during chemical reactions, and that these changes involve the storage or release of energy. The NGSS provide the foundation for understanding why these changes occur. EK 3.C.1 goes beyond the NGSS to list specific changes that might occur, differentiating between physical and chemical changes (**parts b and c**), and requiring identification of precipitation, acid-base, and redox reactions (**part d**).

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.C Chemical and physical transformations may be observed in several ways and typically involve a change in energy.	**3.C.2** Net changes in energy for a chemical reaction can be endothermic or exothermic.	**HS.PS1.A: Structure and Properties of Matter** 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.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.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. **HS.PS3.B: Conservation of Energy and Energy Transfer** Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system.	**HS-PS1-4** 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. **HS-PS3-1** Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).	The NGSS and **AP EK 3.C.2** both describe that chemical reactions can either store energy or release energy. EK 3.C.2 goes beyond the NGSS by using the terms "endothermic" and "exothermic," and by discussing energy diagrams. The NGSS provide the foundation for understanding why these energy changes occur.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.C Chemical and physical transformations may be observed in several ways and typically involve a change in energy.	**3.C.3** Electrochemistry shows the interconversion between chemical and electrical energy in galvanic and electrolytic cells.	**HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. **HS.PS3.B: Conservation of Energy and Energy Transfer** Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system. **HS.PS3.C: Relationship Between Energy and Forces** When two objects interacting through a field change relative position, the energy stored in the field is changed. **HS.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-PS3-1** Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. **HS-PS3-3** Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy. **HS-PS3-5** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	The NGSS provide a foundation for understanding **AP EK 3.C.3**, by describing transfer and conversion of energy, models of energy at the molecular level, and the effects of electric fields. The specific content of EK 3.C.3 goes beyond the NGSS, including redox reactions, galvanic cells, Gibbs free energy, and Faraday's laws.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.A Reaction rates that depend on temperature and other environmental factors are determined by measuring changes in concentrations of reactants or products over time.	**4.A.1** The rate of a reaction is influenced by the concentration or pressure of reactants, the phase of the reactants and products, and environmental factors such as temperature and solvent.	**HS.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.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.	**HS-PS1-5** 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. **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).	The NGSS and **AP EK 4.A.1** both describe reaction rates and the conditions that influence them. EK 4.A.1 goes beyond the NGSS by describing spectroscopic determination of chemical concentration through Beer's law. The NGSS also provide a foundation for understanding EK 4.A.1 by describing the kinetic energy of particles.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.A Reaction rates that depend on temperature and other environmental factors are determined by measuring changes in concentrations of reactants or products over time.	**4.A.3** The magnitude and temperature dependence of the rate of reaction is contained quantitatively in the rate constant.	**HS.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.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.	**HS-PS1-5** 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. **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).	The NGSS provide a foundation for **AP EK 4.A.3** by describing reaction rates and temperature dependence of reaction rates, along with describing the kinetic energy of particles. EK 4.A.3 goes beyond the NGSS with its focus on the rate constant. **EK 4.A.3 part e** is also related to **NGSS HS.PS1.C**.
4.B Elementary reactions are mediated by collisions between molecules. Only collisions having sufficient energy and proper relative orientation of reactants lead to products.	**4.B.2** Not all collisions are successful. To get over the activation energy barrier, the colliding species need sufficient energy. Also, the orientations of the reactant molecules during the collision must allow for the rearrangement of reactant bonds to form product bonds.	**HS.PS1.A: Structure and Properties of Matter** 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.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** 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.	The NGSS provide a foundation for **AP EK 4.B.2** by describing activation energy and collisions of molecules. EK 4.B.2 goes beyond the NGSS by including details of reactant molecule orientation, collision models, and the Maxwell-Boltzmann distribution.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.B Elementary reactions are mediated by collisions between molecules. Only collisions having sufficient energy and proper relative orientation of reactants lead to products.	**4.B.3** A successful collision can be viewed as following a reaction path with an associated energy profile.	**HS.PS1.A: Structure and Properties of Matter** 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.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.PS3.C: Relationship Between Energy and Forces** When two objects interacting through a field change relative position, the energy stored in the field is changed.	**HS-PS1-4** 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. **HS-PS1-5** 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. **HS-PS3-5** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	Both the NGSS and **AP EK 4.B.3** describe chemical reactions as collisions that involve breaking and forming bonds, rearranging atoms, and involving energy. Both also describe the reaction rate being affected by temperature. EK 4.B.3 goes beyond the NGSS by describing reaction coordinates and energy profiles, as well as the Arrhenius equation.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.A Two systems with different temperatures that are in thermal contact will exchange energy. The quantity of thermal energy transferred from one system to another is called heat.	**5.A.1** Temperature is a measure of the average kinetic energy of atoms and molecules.	**MS.PS3.A: Definitions of Energy** Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present. **MS.PS3.B: Conservation of Energy and Energy Transfer** Energy is spontaneously transferred out of hotter regions or objects and into colder ones. **HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. **HS.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. 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.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.	**MS-PS3-3** Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.* **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). **HS-PS3-4** 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).	The NGSS and **AP EK 5.A.1** both include that temperature provides a description of the average kinetic energy of particles (atoms and molecules). EK 5.A.1 goes beyond the NGSS by including a description of the Kelvin temperature scale (**part b**) and of the Maxwell-Boltzmann distribution (**part c**).

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.A Two systems with different temperatures that are in thermal contact will exchange energy. The quantity of thermal energy transferred from one system to another is called heat.	**5.A.2** The process of kinetic energy transfer at the particulate scale is referred to in this course as heat transfer, and the spontaneous direction of the transfer is always from a hot to a cold body.	**HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. **HS.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. 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.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-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). **HS-PS3-4** 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).	Both the NGSS and **AP EK 5.A.2** describe energy transfer from one object to another, kinetic energy of particles association with temperature, and the tendency of systems to move toward a uniform energy distribution. **EK 5.A.2 part f** goes beyond the NGSS by describing specific heat capacities.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.B Energy is neither created nor destroyed, but only transformed from one form to another.	**5.B.1** Energy is transferred between systems either through heat transfer or through one system doing work on the other system.	**HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. **HS.PS3.B: Conservation of Energy and Energy Transfer** Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system. 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.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-PS3-1** Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). **HS-PS3-3** Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy. **HS-PS3-4** 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).	Both the NGSS and **AP EK 5.B.1** describe transfer of energy between objects and from one form to another. **EK 5.B.1 part c** goes beyond the NGSS by explicitly describing work done by a gas.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.B Energy is neither created nor destroyed, but only transformed from one form to another.	**5.B.2** When two systems are in contact with each other and are otherwise isolated, the energy that comes out of one system is equal to the energy that goes into the other system. The combined energy of the two systems remains fixed. Energy transfer can occur though either heat exchange or work.	**HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. **HS.PS3.B: Conservation of Energy and Energy Transfer** Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system. 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.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-PS3-1** Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. **HS-PS3-4** 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).	Both the NGSS and **AP EK 5.B.2** describe the transfer, transformation, and conservation of energy between systems, including the transfer of thermal energy. EK 5.B.2 goes beyond the NGSS by explicitly naming "work."

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.B Energy is neither created nor destroyed, but only transformed from one form to another.	**5.B.3** Chemical systems undergo three main processes that change their energy: heating/cooling, phase transitions, and chemical reactions.	**HS.PS1.A: Structure and Properties of Matter** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. 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.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.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. **HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. **HS.PS3.B: Conservation of Energy and Energy Transfer** Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. *(continued on next page)*	**HS-PS1-3** 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. **HS-PS1-4** 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. **HS-PS3-1** Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).	The NGSS and **AP EK 5.B.3** both describe thermal energy transfer between systems and to the surroundings, and chemical reactions that either store or release energy. The NGSS also provide a foundation for understanding phase transitions by describing kinetic energy of particles (**HS.PS3.A**) and by describing properties of different states of matter, in another section not listed here (**MS.PS1.A**). EK 5.B.3 goes beyond the NGSS by describing specific heat capacity, molar enthalpy of vaporization, and enthalpy change of reactions.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
	5.B.3 Chemical systems undergo three main processes that change their energy: heating/cooling, phase transitions, and chemical reactions.	Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system.		
5.B Energy is neither created nor destroyed, but only transformed from one form to another.	**5.B.4** Calorimetry is an experimental technique that is used to determine the heat exchanged/transferred in a chemical system.	**MS.PS3.A: Definitions of Energy** Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present. **MS.PS3.B: Conservation of Energy and Energy Transfer** The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment. **HS.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. 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.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.	**MS-PS3-4** Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample. **HS-PS3-4** 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).	The NGSS provide a foundation for **AP EK 5.B.4** by describing transfer of thermal energy, conservation of energy, and the connection between temperature and kinetic energy of particles. EK 5.B.4 goes beyond the NGSS by describing the details of calorimetry.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.C Breaking bonds requires energy, and making bonds releases energy.	**5.C.1** Potential energy is associated with a particular geometric arrangement of atoms or ions and the electrostatic interactions between them.	**HS.PS1.A: Structure and Properties of Matter** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. 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.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.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. **HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. **HS.PS3.C: Relationship Between Energy and Forces** When two objects interacting through a field change relative position, the energy stored in the field is changed.	**HS-PS1-3** 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. **HS-PS1-4** 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. **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). **HS-PS3-5** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	The NGSS and **AP EK 5.C.1** both describe energy associated with the configuration of particles and electrostatic interactions between them. Both also describe bond energies. **EK 5.C.1 parts a and e** go beyond the NGSS by describing bond length and atomic vibration, and **EK 5.C.1 part d** describes double and triple bonds.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.C Breaking bonds requires energy, and making bonds releases energy.	**5.C.2** The net energy change during a reaction is the sum of the energy required to break the bonds in the reactant molecules and the energy released in forming the bonds of the product molecules. The net change in energy may be positive for endothermic reactions where energy is required, or negative for exothermic reactions where energy is released.	**HS.PS1.A: Structure and Properties of Matter** 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.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.PS3.A: Definitions of Energy** At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. **HS.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. 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.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-PS1-4** 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. **HS-PS3-3** Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy. **HS-PS3-4** 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).	Both the NGSS and **AP EK 5.C.2** describe bonds broken and formed during chemical reactions, potential and kinetic energy of chemical systems, conservation of energy, and thermal equilibrium. EK 5.C.2 goes beyond the NGSS by describing the details of kinetic and potential energy assumptions that can be made about reactants and products in endothermic vs. exothermic reactions (**part d**), by describing parts of Hess's law (**part f**), and by discussing uses of tables of standard enthalpies of formation (**part g**).

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.D Electrostatic forces exist between molecules as well as between atoms or ions, and breaking the resultant intermolecular interactions requires energy.	**5.D.1** Potential energy is associated with the interaction of molecules; as molecules draw near each other, they experience an attractive force.	**HS.PS1.A: Structure and Properties of Matter** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. 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.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.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. 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. **HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. *(continued on next page)*	**HS-PS1-3** 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. **HS-PS1-4** 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. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). **HS-PS3-5** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	The NGSS and **AP EK 5.D.1** both include discussions of potential energy in chemical systems and of electrostatic interactions between atoms or molecules. EK 5.D.1 goes beyond the NGSS by distinguishing dipole-dipole, dipole-induced dipole, and induced dipole-induced dipole interactions (part a); naming dispersion forces (part b); and describing hydrogen bonding (part c).

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
	5.D.1 Potential energy is associated with the interaction of molecules; as molecules draw near each other, they experience an attractive force.	These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. **HS.PS3.C: Relationship Between Energy and Forces** When two objects interacting through a field change relative position, the energy stored in the field is changed.		
5.D Electrostatic forces exist between molecules as well as between atoms or ions, and breaking the resultant intermolecular interactions requires energy.	**5.D.2** At the particular scale, chemical processes can be distinguished from physical processes because chemical bonds can be distinguished from intermolecular interactions.	**PS1.A: Structure and Properties of Matter** 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. 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. **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-PS1-2** 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. **HS-PS1-4** 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.	The NGSS and **AP EK 5.D.2** both describe bonds breaking and forming in chemical reactions, and also describe intermolecular interactions in different phases of matter. EK 5.D.2 goes beyond the NGSS by comparing chemical versus physical changes and discussing interactions that could be classified either way (e.g., dissolution of a salt in water).

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.D Electrostatic forces exist between molecules as well as between atoms or ions, and breaking the resultant intermolecular interactions requires energy.	**5.D.3** Noncovalent and intermolecular interactions play important roles in many biological and polymer systems.	**HS.PS1.A: Structure and Properties of Matter** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. **HS.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. **HS.LS1.C: Organization for Matter and Energy Flow in Organisms** 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. As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products.	**HS-PS1-3** 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. **HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. **HS-LS1-6** 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.	Both the NGSS and **AP EK 5.D.3** describe the effect of the structure of substances on the properties of those substances. The NGSS also provide a foundation for EK 5.D.3 by describing that large carbon-based molecules (including proteins) are formed from smaller molecules, including carbon, hydrogen, and oxygen. EK 5.D.3 goes beyond the NGSS by describing noncovalent interactions and their effect on the shape of molecules (such as enzymes).

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.E Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.	**5.E.1** Entropy is a measure of the dispersal of matter and energy.	**HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. **HS.PS3.B: Conservation of Energy and Energy Transfer** Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system. 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.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-PS3-1** Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). **HS-PS3-4** 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).	The NGSS build a foundation for **AP EK 5.E.1** by describing that uncontrolled systems always evolve toward a more stable and uniform state, and by describing kinetic energy of particles. EK 5.E.1 goes beyond the NGSS by describing Entropy in detail, including predictions of entropy change.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
6.A Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.	**6.A.1** In many classes of reactions, it is important to consider both the forward and reverse reaction.	**HS.PS1.B: Chemical Reactions** 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.	**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.	Both the NGSS and **AP EK 6.A.1** describe reversible reactions. EK 6.A.1 goes beyond the NGSS by describing specific examples of reversible reactions, such as transfer of protons in acid-base reactions and transfer of electrons in redox reactions.
6.A Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.	**6.A.3** When a system is at equilibrium, all macroscopic variables, such as concentrations, partial pressures, and temperature, do not change over time. Equilibrium results from an equality between the rates of the forward and reverse reactions, at which point *Q=K.*	**HS.PS1.B: Chemical Reactions** 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. **HS.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. 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.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-PS1-6** Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium. **HS-PS3-4** 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).	The NGSS and **AP EK 6.A.3** both describe equilibrium in chemical systems, and reversible reactions. EK 6.A.3 goes beyond the NGSS by including more specificity about equilibrium, including describing Q and K.
6.A Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.	**6.A.4** The magnitude of the equilibrium constant, *K*, can be used to determine whether the equilibrium lies toward the reactant side or produce side.	**HS.PS1.A: Structure and Properties of Matter** 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.B: Chemical Reactions** 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. 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** 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. **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 NGSS and **AP EK 6.A.4** both describe equilibrium in chemical systems, reversible reactions, and properties of elements. EK 6.A.4 goes beyond the NGSS by describing the equilibrium constant, *K*, and its use in making predictions about the outcome of chemical reactions.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
6.B Systems at equilibrium are responsive to external perturbations, with the response leading to a change in the composition of the system.	**6.B.1** Systems at equilibrium respond to disturbances by partially countering the effect of the disturbance (Le Chatelier's principle).	**HS.PS1.B: Chemical Reactions** 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.	**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.	Both the NGSS and **AP EK 6.B.1** describe Le Chatelier's principle. This is explicit in the **HS-PS1-6** clarification statement (not shown). EK 6.B.1 goes beyond the NGSS by specifying stresses that should be used to predict the effect on the system.
6.C Chemical equilibrium plays an important role in acid-base chemistry and in solubility.	**6.C.3** The solubility of a substance can be understood in terms of chemical equilibrium.	**HS.PS1.B: Chemical Reactions** 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.	**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.	Both the NGSS and **AP EK 6.C.3** describe Le Chatelier's principle, reversible reactions, and equilibrium. EK 6.C.3 goes beyond the NGSS by discussing details of solubility and free energy change, and listing particular salts that are soluble in water. This concept is also related to **NGSS HS-PS1-3**.

APPENDIX C
NGSS & AP Physics 1 and 2 Comparison Chart

What was evaluated and compared?

- For this comparison, the specific language of each AP Essential Knowledge (AP EK) statement was compared to the Disciplinary Core Idea (DCI) elements associated with each Next Generation Science Standards (NGSS) Performance Expectation (PE) to determine whether the two share a similar content or conceptual foundation.
- The NGSS and the AP course guides are very different in intended format, audience (the NGSS is for all students whereas the AP course guides cover college-level content), and content emphasis, particularly the emphasis in the NGSS on all three components of the foundation boxes. Therefore, this document focuses solely on the overlap of disciplinary content rather than on any similarities related to the practices or crosscutting concepts. When comparing the AP EK content to the NGSS, only the DCI elements associated with each PE were used in the comparison. This is not to be taken as a devaluation of the practices or crosscutting concepts. A discussion of practices and crosscutting concepts can be found on page 23.

How is the chart organized?

- The charts are organized by the AP EK statements and include some possible DCI elements that overlap with or build a foundation for the AP content in each EK statement. AP EK statements are not included in the course chart if no similarity was found between them and the NGSS content.
- The entirety of the EK text is not included in each row. Most EK statements have a general statement and then multiple supporting parts for the statement. While all parts of the EK text were evaluated for the comparison, the chart only includes the general EK statement. Where appropriate, the comments in each row refer to individual parts of the EK text. For the full EK text, please see the AP Physics 1 and 2 Course and Exam Description from College Board.
- The full text for each identified DCI is not included in the chart. Only the DCI elements that overlap with or provide a foundation for the AP EK statements are included in the chart.

Note: For the purpose of this document, the comparison was only done for AP Physics 1 and AP Physics 2, which are the equivalent of introductory, algebra-based physics college courses. College Board combines the full course descriptions for both introductory Physics courses into one course guide, and accordingly, the comparison between NGSS and both AP Physics courses was done in one chart. The chart differentiates instructional similarity with content in AP Physics 1 by using “P1” and in AP Physics 2 by using “P2.” The College Board’s other two AP physics courses, AP Physics C: Mechanics and AP Physics C: Electricity and Magnetism were not evaluated.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.A The internal structure of a system determines many properties of the system.	**1.A.3** Nuclei have internal structures that determine their properties. (P2)	**HS.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. 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.C: Nuclear Processes** Nuclear processes, including fusion, fission, and 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-PS1-1** 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. **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.	**AP EK 1.A.3** and the NGSS both describe that atomic nuclei have internal structures that determine their properties; that the nucleus is composed of different particles; and that radioactive decay involves the nucleus. The NGSS also contain ideas about other nuclear processes that are beyond the scope of EK 1.A.3.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.A The internal structure of a system determines many properties of the system.	**1.A.4** Atoms have internal structures that determine their properties. (P2)	**HS.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. 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. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. **HS.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. **HS.ESS1.A: The Universe and Its Stars** 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.	**HS-PS1-1** 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. **HS-PS1-3** 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. **HS-ESS1-2** 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.	**AP EK 1.A.4** and the NGSS both describe that atoms have internal structures that determine their properties, including that the number of electrons, or the electrical forces between atoms, determine observable structure and interactions of bulk matter. Both EK 1.A.4 and the NGSS also address the concept of spectra. However, EK 1.A.1 goes beyond the NGSS by relating spectra to distinct atomic transitions, and by identifying the Bohr model and energy transitions.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.A The internal structure of a system determines many properties of the system.	**1.A.5** Systems have properties determined by the properties and interactions of their constituent atomic and molecular substructures. In AP Physics, when the properties of the constituent parts are not important in modeling the behavior of the macroscopic system, the system itself may be referred to as an object. (P1, P2)	**HS.PS1.A: Structure and Properties of Matter** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.	**HS-PS1-3** 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.	**AP EK 1.A.5** and **NGSS HS.PS1.A** both describe that properties of matter can be determined through the electrostatic forces between particles.
1.B Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.	**1.B.2** There are only two kinds of electric charge. Neutral objects or systems contain equal quantities of positive and negative charge, with the exception of some fundamental particles that have no electric charge. (P1, P2)	**MS.PS2.B: Types of Interactions** Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between interacting objects. **HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. **HS.PS3.C: Relationship Between Energy and Forces** When two objects interacting through a field change relative position, the energy stored in the field is changed.	**MS-PS2-3** Ask questions about data to determine the factors that affect the strength of electric and magnetic forces. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. **HS-PS3-5** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	**AP EK 1.B.2** and the NGSS both describe the concept of attractive and repulsive forces in electrostatics, that objects can interact through electric fields, and the concept of the forces between charges.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.C Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.	**1.C.1** Inertial mass is the property of an object or a system that determines how its motion changes when it interacts with other objects or systems. (P1)	**MS.PS2.A: Forces and Motion** The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. All positions of objects and the directions of force and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared. **HS.PS2.A: Forces and Motion** Newton's second law accurately predicts changes in the motion of macroscopic objects.	**MS-PS2-2** Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. **HS-PS2-1** Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.	**AP EK 1.C.1** and the NGSS both describe that objects have mass and that they interact through the exertion of forces. EK 1.C.1 goes beyond the NGSS by identifying the concept of inertial mass.
1.C Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.	**1.C.2** Gravitational mass is the property of an object or a system that determines the strength of the gravitational interaction with other objects, systems, or gravitational fields. (P1)	**MS.PS2.B: Types of Interactions** Gravitational forces are always attractive. There is a gravitational force between any two masses, but it is very small except when one or both of the objects have large mass—e.g., Earth and the sun. **HS.PS2.A: Forces and Motion** Newton's second law accurately predicts changes in the motion of macroscopic objects. **HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects**.** Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.	**MS-PS2-4** Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects. **HS-PS2-1** Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.	**AP EK 1.C.2** and **NGSS HS.PS2.A** both describe that objects have mass and that they interact through the exertion of forces. EK 1.C.2 and **NGSS HS.PS2.B** both describe gravitational fields. EK 1.C.2 connects with **NGSS MS.PS2.B** by identifying the connection between mass as the source of a gravitational field, but goes beyond the NGSS by identifying the common acceleration of objects near the surface of the Earth.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.D Classical mechanics cannot describe all properties of objects.	**1.D.2** Certain phenomena classically thought of as waves can exhibit properties of particles. (P2)	**HS.PS3.A: Definitions of Energy** At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. **HS.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. 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.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-PS3-3** Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy **HS-PS3-4** 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).	**AP EK 1.D.2** and the NGSS both describe the wave-particle duality of electromagnetic radiation and that the energy of electromagnetic radiation is frequency dependent. EK 1.D.2 goes beyond the NGSS by specifically referring to photons.
1.E Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.	**1.E.1** Matter has a property called density. (P2)	**MS.PS1.A: Structure and Properties of Matter** Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it. **MS.PS1.B: Chemical Reactions** Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.	**MS-PS1-2** Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.	**AP EK 1.E.1** and the NGSS both describe density as a property that can be used to identify a substance.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
1.E Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.	**1.E.2** Matter has a property called resistivity. (P1, P2)	**HS.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. 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. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. **HS.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.	**HS-PS1-1** 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. **HS-PS1-3** 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. **HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*	The NGSS establish a foundation for **AP EK 1.E.2** by describing how atomic and molecular structure and interactions determine the properties of matter. EK 1.E.2 goes beyond the NGSS by specifically highlighting resistivity.
1.E Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.	**1.E.3** Matter has a property called thermal conductivity. (P2)	**HS.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. 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. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. **HS.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.	**HS-PS1-1** 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 **HS-PS1-3** 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. **HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*	The NGSS establish a foundation for **AP EK 1.E.3** by identifying how the atomic and molecular structure and interactions determine the properties of matter. **NGSS HS.PS1.A** and **HS.PS2.B** can be applied to explain thermal conductivity, among other properties, and build an understanding towards EK 1.E.3, which focuses specifically on the property of thermal conductivity.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.A A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena.	**2.A.1** A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector. (P1, P2)	**MS.PS2.B: Types of Interactions** Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object, or a ball, respectively). **HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.	**MS-PS2-5** Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects	Both the NGSS and AP describe the concept of fields of force determined by mass or charge. **NGSS HS.PS2.B** establishes a foundation for understanding vectors in **AP EK 2.A.1.**
2.A A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena.	**2.A.2** A scalar field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a scalar. In Physics 2, this should include electric potential. (P2)	**HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.	**HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.	Both the NGSS and AP describe the concept of fields of force determined by mass or charge. **AP EK 2.A.2** goes beyond the NGSS by identifying scalar fields.
2.B A gravitational field is caused by an object with mass.	**2.B.1** A gravitational field g at the location of an object with mass m causes a gravitational force of magnitude mg to be exerted on the object in the direction of the field. (P1)	**HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.	**HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.	**AP EK 2.B.1** and **NGSS HS.PS2.B** both describe that gravitational force results from the interaction between the mass of an object and the gravitational field (Newton's Law of Gravitation).

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.B A gravitational field is caused by an object with mass.	**2.B.2** The gravitational field caused by a spherically symmetric object with mass is radial and, outside the object, varies as the inverse square of the radial distance from the center of that object. (P1)	**HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.	**HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.	**AP EK 2.B.2** and **NGSS HS.PS2.B** both describe how the gravitational force exerted on an object by another object varies with distance between the objects. The NGSS establish a foundation for deeply understanding this concept by describing how fields explain forces acting at a distance.
2.C An electric field is caused by an object with electric charge.	**2.C.1** The magnitude of the electric force **F** exerted on an object with electric charge q by an electric field $\underset{E}{\rightarrow}$ is $\underset{F}{\rightarrow} = q \underset{E}{\rightarrow}$. The direction of the force is determined by the direction of the field and the sign of the charge, with positively charged objects accelerating in the direction of the field and negatively charged objects accelerating in the direction opposite the field. This should include a vector field map for positive point charges, negative point charges, spherically symmetric charge distribution, and uniformly charged parallel plates. (P2)	**MS.PS2.B: Types of Interactions** Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between interacting objects. **HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object, or a ball, respectively).	**MS-PS2-3** Ask questions about data to determine the factors that affect the strength of electric and magnetic forces. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.	**AP EK 2.C.1** and the NGSS both describe Coulomb's law. EK 2.C.1 goes beyond the NGSS by specifying the field of parallel plates.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.C An electric field is caused by an object with electric charge.	**2.C.2** The magnitude of the electric field vector is proportional to the net electric charge of the object(s) creating that field. This includes positive point charges, negative point charges, spherically symmetric charge distributions, and uniformly charged parallel plates. (P2)	**HS.PS2.B: Types of Interaction** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.	**HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.	**AP EK 2.C.2** and the NGSS both describe Coulomb's law. EK 2.C.2 goes beyond the NGSS by specifying types of contributing charges.
2.C An electric field is caused by an object with electric charge.	**2.C.3** The electric field outside a spherically symmetric charged object is radial and its magnitude varies as the inverse square of the radial distance from the center of that object. Electric field lines are not in the curriculum. Students will be expected to rely only on the rough intuitive sense underlying field lines, wherein the field is viewed as analogous to something emanating uniformly from a source. (P2)	**HS.PS2.B: Types of Interaction** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.	**HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.	Both **AP EK 2.C.3** and the NGSS describe Coulomb's law.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
2.D A magnetic field is caused by a magnet or a moving electrically charged object. Magnetic fields observed in nature always seem to be produced either by moving charged objects or by magnetic dipoles or combinations of dipoles and never by single poles.	**2.D.1** The magnetic field exerts a force on a moving electrically charged object. That magnetic force is perpendicular to the direction of velocity of the object and to the magnetic field and is proportional to the magnitude of the charge, the magnitude of the velocity, and the magnitude of the magnetic field. It also depends on the angle between the velocity and the magnetic field vectors. Treatment is quantitative for angles of 0°, 90°, or 180° and qualitative for other angles. (P2)	**HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. **PS3.A: Definitions of Energy** "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents.	**HS-PS2-5** Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.	Both the NGSS and AP describe that electrical and magnetic fields can interact with one another. The NGSS establish a foundation for **AP EK 2.D.1** by describing that electric currents contribute to the production of magnetic fields. EK 2.D.1 goes beyond the NGSS and builds on this understanding with the concepts of magnitude of charge, and geometry, magnitude, and orientation of the field.
2.D A magnetic field is caused by a magnet or a moving electrically charged object. Magnetic fields observed in nature always seem to be produced either by moving charged objects or by magnetic dipoles or combinations of dipoles and never by single poles.	**2.D.2** The magnetic field vectors around a straight wire that carries electric current are tangent to concentric circles centered on the wire. The field has no component toward the current-carrying wire. (P2)	**HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. **PS3.A: Definitions of Energy** "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents.	**HS-PS2-5** Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.	Both the NGSS and AP describe interactions between electric currents and magnetic fields. **AP EK 2.D.2** builds on the conceptual foundation established in the NGSS with more sophisticated concepts of magnitude and orientation of the field.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.A All forces share certain common characteristics when considered by observers in inertial reference frames.	**3.A.1** An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. (P1)	**MS.PS2.A: Forces and Motion** The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared. **HS.PS2.A: Forces and Motion** Newton's second law accurately predicts changes in the motion of macroscopic objects. Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.	**MS-PS2-2** Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. **HS-PS2-1** Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. **HS-PS2-2** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system	The NGSS and AP both describe observable quantities that must be defined and described from a specific frame of reference**.**

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.A All forces share certain common characteristics when considered by observers in inertial reference frames.	**3.A.2** Forces are described by vectors. (P1, P2)	**MS.PS2.A: Forces and Motion** The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared. **HS.PS2.A: Forces and Motion** Newton's second law accurately predicts changes in the motion of macroscopic objects.	**MS-PS2-2** Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. **HS-PS2-1** Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.	**AP EK 3.A.2** and **NGSS HS.PS2.A** and **MS.PS2.A** describe the change in the motion of an object due to net force acting on it. EK 3.A.2 builds on the NGSS by including vector descriptions of forces, which allow for more sophisticated descriptions of the resulting motion.
3.A All forces share certain common characteristics when considered by observers in inertial reference frames.	**3.A.3** A force exerted on an object is always due to the interaction of that object with another object. (P1, P2)	**MS.PS2.A: Forces and Motion** For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law).	**MS-PS2-1** Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.	Both AP and the NGSS describe how objects interact with one another through forces.
3.A All forces share certain common characteristics when considered by observers in inertial reference frames.	**3.A.4** If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction. (P1, P2)	**MS.PS2.A: Forces and Motion** For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law).	**MS-PS2-1** Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.	The NGSS and AP both describe how objects interact with one another through forces.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.B Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\Sigma\vec{F}}{m}$.	**3.B.1** If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. (P1, P2)	**MS.PS2.A: Forces and Motion** For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law). **HS.PS2.A: Forces and Motion** Newton's second law accurately predicts changes in the motion of macroscopic objects.	**MS-PS2-1** Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects. **HS-PS2-1** Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.	The NGSS and AP both describe how objects interact through forces. **NGSS MS.PS2.A** identifies Newton's third law and **NGSS HS.PS2.A** identifies Newton's second law. Each law contributes to an understanding of the interaction between several objects described in **AP EK 3.B.1.** EK 3.B.1 diverges from the NGSS by identifying the idea of expressing forces as a vector sum.
3.C At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.	**3.C.1** Gravitational force describes the interaction of one object that has mass with another object that has mass. (P1)	**MS.PS2.B: Types of Interaction** Gravitational forces are always attractive. There is a gravitational force between any two masses, but it is very small except when one or both of the objects have large mass—e.g., Earth and the sun. **HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.	**MS-PS2-4** Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.	Both the NGSS and AP describe Newton's law of universal gravitation.
3.C At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.	**3.C.2** Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge. (P1, P2)	**HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.	**HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.	Both the NGSS and AP describe the electrostatic forces between objects.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.C At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.	**3.C.3** A magnetic force results from the interaction of a moving charged object or a magnet with other moving charged objects or another magnet. (P2)	**MS.PS2.B: Types of Interactions** Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object, or a ball, respectively).	**MS-PS2-5** Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.	**AP EK 3.C.3** and the NGSS both describe forces between objects. EK 3.C.3 diverges from the NGSS by identifying concepts related to the sources and orientations of a magnetic field as well the force on moving charged particles.
3.D A force exerted on an object can change the momentum of the object.	**3.D.1** The change in momentum of an object is a vector in the direction of the net force exerted on the object. (P1)	**HS.PS2.A: Forces and Motion** Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.	**HS-PS2-2** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. **HS-PS2-3** Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*	**AP EK 3.D.1** and **NGSS HS.PS2.A** both describe that forces exerted on a system can change the momentum of the system. The NGSS limits vector calculations to one-dimensional vectors.
3.D A force exerted on an object can change the momentum of the object.	**3.D.2** The change in momentum of an object occurs over a time interval. (P1)	**HS.PS2.A: Forces and Motion** Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.	**HS-PS2-2** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. **HS-PS2-3** Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*	**AP EK 3.D.2** and **NGSS HS.PS2.A** both describe that momentum is defined for a specific reference frame; in this case, a specific time interval.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.E A force exerted on an object can change the kinetic energy of the object	**3.E.1** The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the time interval that the force is exerted. (P1)	**MS.PS3.A: Definitions of Energy** Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed. **MS.PS3.B: Conservation of Energy and Energy Transfer** When the motion energy of an object changes, there is inevitably some other change in energy at the same time. **HS.PS3.B:** Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. **MS.PS3.C: Relationship Between Energy and Forces** When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object. **HS.PS3.C: Relationship Between Energy and Forces** When two objects interacting through a field change relative position, the energy stored in the field is changed.	**MS-PS3-1** Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object. **MS-PS3-2** Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system. **MS-PS3-5** Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object. **HS-PS3-1** Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. **HS-PS3-5** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	The NGSS and AP both describe kinetic energy and its relationship to the motion and mass of objects (at all scales). They also both describe that the motion of an object changes as a result of forces exerted on the object.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.G Certain types forces are considered fundamental.	**3.G.1** Gravitational forces are exerted at all scales and dominate at the largest distance and mass scales. (P1, P2)	**MS.ESS1.A: The Universe and Its Stars** Earth and its solar system are part of the Milky Way galaxy, which is one of many galaxies in the universe. **MS.ESS1.B: Earth and the Solar System** The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them. The solar system appears to have formed from a disk of dust and gas, drawn together by gravity. **HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. **HS.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. **HS.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.	**MS-ESS1-2** Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system. **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. **HS-ESS1-4** Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.	Both the AP and NGSS describe that gravitational forces exist at varying scales, and both emphasize that gravity plays a critical role in governing interactions between objects and extremely large spatial and mass scales (e.g., stellar scales).

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
3.G Certain types forces are considered fundamental.	**3.G.2** Electromagnetic forces are exerted at all scales and can dominate at the human scale. (P2)	**HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. **HS.PS4.B: Electromagnetic Radiation** Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features.	**HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. **HS-PS4-3** Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.	Both the AP and the NGSS describe electromagnetic forces involving charged objects. The NGSS establish a foundation for understanding **AP EK 3.G.2** by developing an understanding of physical interactions between electrically charged objects (this understanding builds across grade levels in the NGSS), electric and magnetic fields, and the energy transfer/transport resulting from electromagnetic field propagation (EM radiation).
3.G Certain types forces are considered fundamental.	**3.G.3** The strong force is exerted at nuclear scales and dominates the interactions of nucleons. (P2)	**HS.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.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. **HS.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. 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.	**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. **HS-ESS1-1** 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. **HS-ESS1-3** Communicate scientific ideas about the way stars, over their life cycle, produce elements.	The NGSS establish a foundation for understanding the strong force, and the scale at which its impact is dominant, by describing nuclear processes as well as what happens to nuclear particles (e.g., protons and neutrons) during those processes. **AP EK 3.G.3** goes beyond the NGSS by explicitly considering the strong force as the force that holds a nucleus together, and governs the interactions at the nuclear scale.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.A The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \frac{\sum \vec{F}}{m}$.	**4.A.1** The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass. (P1)	**MS.PS2.A: Forces and Motion** For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law). The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared. **HS.PS2.A: Forces and Motion** Newton's second law accurately predicts changes in the motion of macroscopic objects. Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.	**MS-PS2-1** Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding bjects.* **MS-PS2-2** Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. **HS-PS2-1** Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. **HS-PS2-2** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.	The NGSS and AP both describe observable quantities that must be defined and described from a specific frame of reference**. AP 4.A.1** explicitly describes this understanding for the linear motion of an object.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.A The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \frac{\sum \vec{F}}{m}$.	**4.A.2** The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time. (P1)	**MS.PS2.A: Forces and Motion** For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law). The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared. **HS.PS2.A: Forces and Motion** Newton's second law accurately predicts changes in the motion of macroscopic objects. Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.	**MS-PS2-1** Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.* **MS-PS2-2** Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. **HS-PS2-1** Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. **HS-PS2-2** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.	The NGSS and AP both describe observable quantities that must be defined and described from a specific frame of reference**. AP EK 4.A.2** diverges from **NGSS HS.PS2.A** by identifying force and acceleration as vectors.
4.B Interactions with other objects or systems can change the total linear momentum of a system.	**4.B.1** The change in linear momentum for a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass. (P1)	**HS.PS2.A: Forces and Motion** Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.	**HS-PS2-2** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.	**AP EK 4.B.1** and **NGSS HS.PS2.A** both describe the concept of momentum.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.B Interactions with other objects or systems can change the total linear momentum of a system.	**4.B.2** The change in linear momentum of the system is given by the product of the average force on that system and the time interval during which the force is exerted. (P1)	**HS.PS2.A: Forces and Motion** Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.	**HS-PS2-2** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. **HS-PS2-3** Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*	**AP EK 4.B.2** and **NGSS HS.PS2.A** both describe momentum as an interaction between the velocity of an object at a given time interval and its mass. EK 4.B.2 builds on conceptual ideas about momentum and velocity in the NGSS by describing changes in momentum in terms of the change in force over a relevant time interval.
4.C Interactions with other objects or systems can change the total energy of a system.	**4.C.1** The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples should include gravitational potential energy, elastic potential energy, and kinetic energy. (P1)	**MS.PS3.A: Definitions of Energy** A system of objects may also contain stored (potential) energy, depending on their relative positions. **MS.PS3.C: Relationship Between Energy and Forces** When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object. **HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.	**MS-PS3-2** Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system. **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).	Both the NGSS and AP define energy and identify examples of different types of energy within systems. **AP EK 4.C.1** goes beyond the NGSS by including elastic potential energy as an example.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.C Interactions with other objects or systems can change the total energy of a system.	**4.C.2** Mechanical energy (the sum of kinetic and potential energy) is transferred into or out of a system when an external force is exerted on a system such that a component of the force is parallel to its displacement. The process through which the energy is transferred is called work. (P1)	**MS.PS3.B: Conservation of Energy and Energy Transfer** When the motion energy of an object changes, there is inevitably some other change in energy at the same time. **HS.PS3.C: Relationship Between Energy and Forces** When two objects interacting through a field change relative position, the energy stored in the field is changed.	**MS-PS3-5** Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object. **HS-PS3-5** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	Both the AP and NGSS describe that energy is transferred into or out of a system when the motion energy of an object changes as a result of an applied force. **AP EK 4.C.2** diverges from the NGSS by defining work as the vector of the product between the force and displacement.
4.C Interactions with other objects or systems can change the total energy of a system.	**4.C.3** Energy is transferred spontaneously from a higher temperature system to a lower temperature system. This process of transferring energy is called heating. The amount of energy transferred is called heat. (P2)	**MS.PS3.A: Definitions of Energy** Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present. **MS.PS3.B: Conservation of Energy and Energy Transfer** Energy is spontaneously transferred out of hotter regions or objects and into colder ones. The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment. **HS.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. 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.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.	**MS-PS3-3** Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer **MS-PS3-4** Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample. **HS-PS3-4** 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).	Both the NGSS and AP describe thermal energy transfer. **AP EK 4.C.3** diverges from the NGSS by including processes of thermal energy transfer, a discussion of scales of energy transfer, and a discussion of molecular motion.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
4.C Interactions with other objects or systems can change the total energy of a system.	**4.C.4** Mass can be converted into energy, and energy can be converted into mass. (P2)	**HS.PS1.C: Nuclear Processes** Nuclear processes, including fusion, fission, and 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.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. **HS.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-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. **HS-ESS1-1** 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.	The NGSS and **AP EK 4.C.4** both describe the idea that nuclear processes include fission, fusion, and nuclear decay, and that these processes involve the absorption and emission of energy. **NGSS HS.PS1.C** also identifies that the total number of nucleons does not change during these processes. **EK 4.C.4 part a** expands on these ideas, by explaining how mass can be converted to energy and vice versa.
4.E The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems.	**4.E.2** Changing magnet flux induces an electric field that can establish an induced emf in a system. (P2)	**HS.PS2.B: Types of Interactions** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. **HS.PS3.A: Definitions of Energy** "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents.	**HS-PS2-5** Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.	**AP EK 4.E.2** and **NGSS HS.PS2.B** both describe the connection between magnetic fields and electric currents. EK 4.E.2 goes beyond the NGSS by discussing magnetic flux and conservation of energy.
5.A Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.	**5.A.1** A system is an object or a collection of objects. The objects are treated as having no internal structure. (P1)	**HS.PS2.A: Forces and Motion** Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.	**HS-PS2-2** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.	The NGSS establish an understanding for systems and interactions within and between systems. **AP EK 5.A.1** explicitly includes a discussion of systems without internal structures, which may support understanding how systems are defined.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.A Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.	**5.A.2** For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings. (P1)	**HS.PS2.A: Forces and Motion** Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system. **HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. **HS.PS3.B: Conservation of Energy and Energy Transfer** Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system. **HS.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-PS2-2** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. **HS-PS2-3** Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.* **HS-PS3-1** Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). **HS-PS3-3** Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*	**AP EK 5.A.2** and the NGSS both describe ideas of momentum, systems of objects, and conservation of energy. EK 5.A.2 goes beyond the NGSS by defining open and closed systems.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.B The energy of a system is conserved.	**5.B.1** Classically, an object can only have kinetic energy since potential energy requires an interaction between two or more objects. (P1)	**HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.	**HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).	**AP EK 5.B.1** and **NGSS MS.PS3.A** both describe that energy can be associated with motion of an object (kinetic energy), and that relative positions between objects requires more than one object. Both the NGSS and AP emphasize system definition, and that energy interactions and measurements are dependent on how a system is defined and the scale at which it is examined (e.g., if a system is a single object at the macro scale, potential energy cannot be defined).

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.B The energy of a system is conserved.	**5.B.2** A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy. [Physics 1: includes mass-spring oscillators and simple pendulums. Physics 2: includes charged object in electric fields and examining changes in internal energy with changes in configuration] (P1, P2)	**HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. **HS.PS3.B: Conservation of Energy and Energy Transfer** Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system.	**HS-PS3-1** Create a computational model to calculate the change in the energy of one component in a system when the c change in energy of the other component(s) and energy flows in and out of the system are known. **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).	**AP EK 5.B.2** and the NGSS both describe that energy can be associated with a system of interacting objects through motion and positions of objects (e.g., particles, macroscopic objects) within a given system.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.B The energy of a system is conserved.	**5.B.3** A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces. (P1)	**MS.PS3.A: Definitions of Energy** A system of objects may also contain stored (potential) energy, depending on their relative positions. **MS.PS3.C: Relationship Between Energy and Forces** When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object. **HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. **HS.PS3.B: Conservation of Energy and Energy Transfer** Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system.	**MS-PS3-2** Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system. **HS-PS3-1** Create a computational model to calculate the change in the energy of one component in a system when change in energy of the other component(s) and energy flows in and out of the system are known. **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).	**AP EK 5.B.3** and the NGSS both describe that a system can have potential energy. EK 5.B.3 diverges from the NGSS by developing ideas about conservative forces.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.B The energy of a system is conserved.	**5.B.4** The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of configuration of the objects that make up the system. (P1, P2)	**MS.PS3.A: Definitions of Energy** Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present. **MS.PS3.B: Conservation of Energy and Energy Transfer** The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment. **HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. **HS.PS3.B: Conservation of Energy and Energy Transfer** Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system.	**MS-PS3-4** Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample. **HS-PS3-1** Create a computational model to calculate the change in the energy of one component in a system when change in energy of the other component(s) and energy flows in and out of the system are known. **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).	**AP EK 5.B.4** and the NGSS both describe that a system can have potential and kinetic energy.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.B The energy of a system is conserved.	**5.B.5** Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance. This process is called doing work on a system. The amount of energy transferred by this mechanical process is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. [A piston filled with gas getting compressed or expanded is treated in Physics 2 as a part of thermodynamics.] (P1, P2)	**HS.PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. **HS.PS3.B: Conservation of Energy and Energy Transfer** Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system. **HS.PS3.C: Relationship Between Energy and Forces** When two objects interacting through a field change relative position, the energy stored in the field is changed. **HS.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-PS3-1** Create a computational model to calculate the change in the energy of one component in a system when change in energy of the other component(s) and energy flows in and out of the system are known. **HS-PS3-3** Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.* **HS-PS3-5** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	**AP EK 5.B.5** and the NGSS both describe that energy can be transferred into or out of a system. **NGSS HS.PS3.C** makes the connection between force (only electric or magnetic) and the change in energy. EK 5.B.5 goes beyond the NGSS by developing ideas relating to the rate of energy transfer and defining work and power.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.B The energy of a system is conserved.	**5.B.6** Energy can be transferred by thermal processes involving differences in temperature; the amount of energy transferred in this process of transfer called heat. (P2)	**MS.PS3.A: Definitions of Energy** Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present. **MS.PS3.B: Conservation of Energy and Energy Transfer** Energy is spontaneously transferred out of hotter regions or objects and into colder ones. The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment. **HS.PS3.B: Conservation of Energy and Energy Transfe**r Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. 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.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.	**MS-PS3-3** Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.* **MS-PS3-4** Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample. **HS-PS3-4** 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).	**AP EK 5.B.6** and the NGSS both describe the transfer of energy involving thermal processes involving temperature differences.
5.D The linear momentum of a system is conserved.	**5.D.1** In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after. (P1, P2)	**HS.PS2.A: Forces and Motion** Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.	**HS-PS2-2** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. **HS-PS2-3** Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*	**AP EK 5.D.1** and **NGSS HS.PS2.A** both describe ideas of collisions, force, and momentum. EK 5.D.1 goes beyond the NGSS by including details about elastic collisions.
5.D The linear momentum of a system is conserved.	**5.D.2** In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision. (P1, P2)	**HS.PS2.A: Forces and Motion** Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.	**HS-PS2-2** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. **HS-PS2-3** Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*	**AP EK 5.D.2** and **NGSS HS.PS2.A** both describe ideas of collisions, force, and momentum. EK 5.D.2 goes beyond the NGSS by explicitly addressing inelastic collisions.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
5.G Nucleon number is conserved.	**5.G.1** The possible nuclear reactions are constrained by the law of conservation of nucleon number. (P2)	**HS.PS1.C: Nuclear Processes** Nuclear processes, including fusion, fission, and 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** 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.	**AP EK 5.G.1** and **NGSS HS.PS1.C** both describe that the total number of neutrons plus protons does not change in nuclear reactions.
6.A A wave is a traveling disturbance that transfers energy and momentum.	**6.A.2** For propagation, mechanical waves require a medium, while electromagnetic waves do not require a physical medium. Examples should include light traveling through a vacuum and sound not traveling through a vacuum. (P1, P2)	**MS.PS4.A: Wave Properties** A sound wave needs a medium through which it is transmitted. **MS.PS4.B: Electromagnetic Radiation** When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends. A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media. However, because light can travel through space, it cannot be a matter wave, like sound or water waves. **HS.PS4.A: Wave Properties** The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing.	**MS-PS4-2** Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. **HS-PS4-1** Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.	**AP EK 6.A.2** and the NGSS both describe that waves travel through mediums, and that mechanical waves require a physical medium while electromagnetic waves do not.
6.A A wave is a traveling disturbance that transfers energy and momentum.	**6.A.3** The amplitude is the maximum displacement of a wave from its equilibrium value. (P1)	**MS.PS4.A: Wave Properties** A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude.	**MS-PS4-1** Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.	**AP EK 6.A.3** and **NGSS MS.PS4.A** both include amplitude as a property of a wave.
6.A A wave is a traveling disturbance that transfers energy and momentum.	**6.A.4** Classically, the energy carried by a wave depends upon and increases with amplitude. Examples should include sound waves. (P1)	**MS.PS4.A: Wave Properties** A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude.	**MS-PS4-1** Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.	**AP EK 6.A.4** and **NGSS MS.PS4.A** both describe the relationship between the amplitude and energy of a wave.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
6.B A periodic wave is one that repeats as a function of both time and position and can be described by its amplitude, frequency, wavelength, speed, and energy.	**6.B.1** For a periodic wave, the period is the repeat time of the wave. The frequency is the number of repetitions of the wave per unit time. (P1)	**MS.PS4.A: Wave Properties** A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude. **HS.PS4.A: Wave Properties** The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing.	**MS-PS4-1** Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave. **HS-PS4-1** Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.	**AP EK 6.B.1** and the NGSS both describe a simple model of the wave, including frequency.
6.B A periodic wave is one that repeats as a function of both time and position and can be described by its amplitude, frequency, wavelength, speed, and energy.	**6.B.2** For a periodic wave, the wavelength is the repeat distance of the wave. (P1)	**MS.PS4.A: Wave Properties** A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude. **HS.PS4.A: Wave Properties** The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing.	**MS-PS4-1** Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave. **HS-PS4-1** Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.	**AP EK 6.B.2** and the NGSS both describe a simple model of the wave, including wavelength.
6.B A periodic wave is one that repeats as a function of both time and position and can be described by its amplitude, frequency, wavelength, speed and energy.	**6.B.3** A simple wave can be described by an equation involving one sine or cosine function involving the wavelength, amplitude, and frequency of the wave. (P2)	**MS.PS4.A: Wave Properties** A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude. **HS.PS4.A: Wave Properties** The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing.	**MS-PS4-1** Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave. **HS-PS4-1** Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.	**AP EK 6.B.3** and the NGSS both describe a mathematical representation of a wave.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
6.E The direction of propagation of a wave such as light may be changed when the wave encounters an interface between two media.	**6.E.1** When light travels from one medium to another, some of the light is transmitted, some is reflected, and some is absorbed. (Qualitative understanding only.) (P2)	**MS.PS4.A: Wave Properties** A sound wave needs a medium through which it is transmitted. **MS.PS4.B: Electromagnetic Radiation** When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends. A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media. However, because light can travel through space, it cannot be a matter wave, like sound or water waves. **HS.PS4.B: Electromagnetic Radiation** When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells.	**MS-PS4-2** Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. **HS-PS4-4** Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.	**AP EK 6.E.1** and the NGSS both describe that light can be transmitted, reflected, or absorbed.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
6.E The direction of propagation of a wave such as light may be changed when the wave encounters an interface between two media.	**6.E.2** When light hits a smooth reflecting surface at an angle, it reflects at the same angle on the other side of the line perpendicular to the surface (specular reflection); this law of reflection accounts for the size and location of images seen in mirrors. (P2)	**MS.PS4.A: Wave Properties** A sound wave needs a medium through which it is transmitted. **MS.PS4.B: Electromagnetic Radiation** When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends. A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media. However, because light can travel through space, it cannot be a matter wave, like sound or water waves.	**MS-PS4-2** Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.	**AP EK 6.E.2** and the NGSS both describe that light can be reflected. EK 6.E.2 goes beyond the NGSS by introducing the law of reflection.
6.E The direction of propagation of a wave such as light may be changed when the wave encounters an interface between two media.	**6.E.3** When light travels across a boundary from one transparent material to another, the speed of propagation changes. At a non-normal incident angle, the path of the light ray bends closer to the perpendicular in the optically slower substance. This is called refraction. (P2)	**MS.PS4.A: Wave Properties** A sound wave needs a medium through which it is transmitted. **MS.PS4.B: Electromagnetic Radiation** When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends. A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media. However, because light can travel through space, it cannot be a matter wave, like sound or water waves.	**MS-PS4-2** Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.	**AP EK 6.E.3** and the NGSS both describe that light can be transmitted. EK 6.A.3 goes beyond the NGSS with a definition of refraction. The vocabulary introduced in AP builds on the conceptual understanding of light bending established in the NGSS.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
6.F Electromagnetic radiation can be modeled as waves or as fundamental particles.	**6.F.1** Types of electromagnetic radiation are characterized by their wavelengths, and certain ranges of wavelength have been given specific names. These include (in order of increasing wavelength spanning a range from picometers to kilometers) gamma rays, x-rays, ultraviolet, visible light, infrared, microwaves, and radio waves. (P2)	**HS.PS4.A: Wave Properties** Wave Properties [From the 3–5 grade band endpoints] Waves can add or cancel one another as they cross, depending on their relative phase (i.e., relative position of peaks and troughs of the waves), but they emerge unaffected by each other. The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing. **HS.PS4.B: Electromagnetic Radiation** Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells.	**HS-PS4-1** Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media. **HS-PS4-3** Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other. **HS-PS4-4** Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.	**AP EK 6.F.1** and the NGSS both describe that there are different wavelengths and frequencies of light.
6.F Electromagnetic radiation can be modeled as waves or as fundamental particles.	**6.F.2** Electromagnetic waves can transmit energy through a medium and through a vacuum. (P2)	**HS.PS4.A: Wave Properties** The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing.	**HS-PS4-1** Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.	**AP EK 6.F.2** and the NGSS both describe that waves can travel through mediums and that electromagnetic waves propagate though a vacuum.
6.F Electromagnetic radiation can be modeled as waves or as fundamental particles.	**6.F.3** Photons are individual energy packets of electromagnetic waves, with $E_{photon}=hf$, where h is Planck's constant and f is the frequency of the associated light wave. (P2)	**HS.PS4.A: Wave Properties** [From the 3–5 grade band endpoints] Waves can add or cancel one another as they cross, depending on their relative phase (i.e., relative position of peaks and troughs of the waves), but they emerge unaffected by each other. **HS.PS4.B: Electromagnetic Radiation** Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features.	**HS-PS4-3** Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.	**AP EK 6.F.3** and the NGSS both detail that light waves can be described as particles. **AP EK 6.F.3** goes beyond the NGSS by describing ideas such as Planck's constant and the quantum model.

AP Enduring Understanding	AP Essential Knowledge Focus	NGSS Disciplinary Core Idea Element(s)	NGSS Performance Expectation(s)	Comments about the Connections
6.F Electromagnetic radiation can be modeled as waves or as fundamental particles.	**6.F.4** The nature of light requires that different models of light are most appropriate at different scales. (P2)	**HS.PS4.A: Wave Properties** Wave Properties [From the 3–5 grade band endpoints] Waves can add or cancel one another as they cross, depending on their relative phase (i.e., relative position of peaks and troughs of the waves), but they emerge unaffected by each other. (Boundary: The discussion at this grade level is qualitative only; it can be based on the fact that two different sounds can pass a location in different directions without getting mixed up.) **HS.PS4.B: Electromagnetic Radiation** Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features.	**HS-PS4-3** Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.	Both the NGSS and AP describe that light may be represented by either a wave model or a particle model. **AP EK 6.F.4** goes beyond the NGSS by describing the implications of scale for the two models.