High School Modified Domains Model Course II - Physics
Bundle 2: How Do We Protect Ourselves From Collisions?

This is the second bundle of the High School Domains Model Course II - Physics. Each bundle has connections to the other bundles in the course, as shown in the Course Flowchart.

Bundle 2 Question: This bundle is assembled to address the question "how do we protect ourselves from collisions?"

Summary

The bundle organizes performance expectations with a focus on helping students understand forces and collisions at the macroscopic scale. Instruction developed from this bundle should always maintain the three-dimensional nature of the standards, but recognize that instruction is not limited to the practices and concepts directly linked with any of the bundle performance expectations.

Connections between bundle DCIs

Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object relative to the reference frame (PS2.A as in HS-PS2-2). While momentum within a system is conserved, the total momentum of a system can change if a system interacts with objects outside itself; however, these changes are balanced by changes in the momentum of objects outside the system (PS2.A as in HS-PS2-2 and HS-PS2-3). These ideas connect to the concepts about the motion objects, including that Newton's second law accurately predicts changes in the motion of macroscopic objects (PS2.A as in HS-PS2-1) while Kepler's laws describe common features of the motions of orbiting objects (ESS1.B as in HS-ESS1-4).

The concepts about momentum changes in systems and about Kepler's laws connect to ideas about the motion of objects within and outside of our solar system at different scales. In addition to the common features of the motions of orbiting objects described by Kepler's laws, the motion of objects outside our solar system, such as the motions of other solar systems and galaxies, can be understood through the Big Bang theory. 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 that still fills the universe (ESS1.A as in HS-ESS1-2). These ideas about the kinds of observations that provide astronomical evidence for the Big Bang theory connect to the concept that studying the light spectra and brightness of stars aids in the identification of compositional elements of stars, their movements, and their distances from Earth (ESS1.A as in HS-ESS1-2), and to the idea that atoms of each element emit and absorb characteristic frequencies of light which allow identification of the presence of an element, even in microscopic quantities (PS4.B as in HS-ESS1-2).

The engineering design concept that criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them (ETS1.A as in HS-ETS1-1) could be applied to a variety of science concepts, such as definitions of momentum as the mass times the velocity of the object (PS2.A as in HS-PS2-2) and balance of momentum changes within a given system by changes in the momentum of interacting objects outside the system (PS2.A as in HS-PS2-2, HS-PS2-3). Connections could be made through engineering design tasks such as identifying the criteria and constraints for designing safer vehicles or developing more energy efficient modes of transportation.

When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts (ETS1.B as in HS-ETS1-3). This engineering design concept connects to other engineering concepts about criteria and constraints (ETS1.A as in HS-ETS1-1) and could also be applied to a variety of science concepts, including that momentum is the mass times the velocity of the object (PS2.A as in HS-PS2-2) or that if a system interacts with objects outside itself, any change in the system is balanced by changes in the momentum of objects outside the system (PS2.A as in HS-PS2-2, HS-PS2-3). Connections could be made through engineering design tasks such as taking into account a range of constraints for the development of energy production technologies such as generators, wind turbines, or small motors, or for the design of amusement park rides such as roller coasters, water rides, or merry-go-rounds.

Bundle Science and Engineering Practices
Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of defining problems (HS-ETS1-1), analyzing data (HS-PS2-1), using mathematical and computational representations (HS-PS2-2 and HS-ESS1-4), and constructing explanations and designing solutions (HS-PS2-3, HS-ESS1-2, and HS-ETS1-3). Many other practice elements can be used in instruction.

Bundle Crosscutting Concepts
Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the crosscutting concepts of Cause and Effect (HS-PS2-1 and HS-PS2-3), Scale, Proportion, and Quantity (HS-ESS1-4), Systems and System Models (HS-PS2-2), and Energy and Matter (HS-ESS1-2). Many other crosscutting concept elements can be used in instruction.

All instruction should be three-dimensional.

Performance Expectations	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.** [Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled by a constant force.] [Assessment Boundary: Assessment is limited to one dimensional motion and to macroscopic objects moving at non-relativistic speeds.] 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.** [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.] 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.*** [Clarification Statement: Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute.] [Assessment Boundary: Assessment is limited to qualitative evaluations and/or algebraic manipulations.] 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.** [Clarification Statement: Emphasis is on the astronomical evidence of the red shift of light from galaxies as an indication that the universe is currently expanding, the cosmic microwave background as the remnant radiation from the Big Bang, and the observed composition of ordinary matter of the universe, primarily found in stars and interstellar gases (from the spectra of electromagnetic radiation from stars), which matches that predicted by the Big Bang theory (3/4 hydrogen and 1/4 helium).] HS-ESS1-4. **Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.** [Clarification Statement: Emphasis is on Newtonian gravitational laws governing orbital motions, which apply to human-made satellites as well as planets and moons.] [Assessment Boundary: Mathematical representations for the gravitational attraction of bodies and Kepler's Laws of orbital motions should not deal with more than two bodies, nor involve calculus.] HS-ETS1-1. **Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.**

Performance Expectations (Continued)	HS-ETS1-3. **Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.**
Example Phenomena	Fewer people die in car accidents when they have airbags versus those who don't have airbags. When one billiard ball strikes another billiard ball, the first ball might stop while the second ball starts moving.
Additional Practices Building to the PEs	**Asking Questions and Defining Problems** • Ask questions to clarify and refine a model, an explanation, or an engineering problem. Students could *ask questions to clarify and refine an explanation* [for how] ***if a system interacts with objects outside itself, the total momentum of the system can change***. HS-PS2-2 and HS-PS2-3 **Developing and Using Models** • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. Students could *use a model based on evidence to predict relationships* [of distance between our galaxy and] ***distant galaxies*** [based on] ***the Big Bang theory***. HS-ESS1-2 **Planning and Carrying Out Investigations** • Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. Students could *plan an investigation to produce data to serve as the basis for evidence* [that] ***momentum is the mass times the velocity of an object***. HS-PS2-2 **Analyzing and Interpreting Data** • Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. Students could *consider limitations of data analysis when analyzing and interpreting data* [on how] ***orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system***. HS-ESS1-4 **Using Mathematical and Computational Thinking** • Apply techniques of algebra and functions to represent and solve scientific and engineering problems. Students could *apply techniques of algebra and functions to represent and solve engineering problems* [related to how] ***orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system***. HS-ESS1-4

Additional Practices Building to the PEs (Continued)	**Constructing Explanations and Designing Solutions** • Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. Students could *apply scientific reasoning and models to assess the extent to which the reasoning and data support the explanation* [that] ***orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system***. HS-ESS1-4 **Engaging in Argument from Evidence** • Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence. Students could *construct and present an oral written argument based on data and evidence* [that] ***momentum is the mass times the velocity of the object***. HS-PS2-2 **Obtaining, Evaluating, and Communicating Information** • Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). Students could *communicate scientific information* [about how] ***observations of the maps of spectra of the primordial radiation that fills the universe support the Big Bang theory***. HS-ESS1-2
Additional Crosscutting Concepts Building to the PEs	**Patterns** • Empirical evidence is needed to identify patterns. Students could describe why *empirical evidence to identify* [the] *pattern* [that] ***Newton's second law accurately predicts changes in the motion of macroscopic objects***. HS-PS2-1 **Cause and Effect** • Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. Students could *suggest cause and effect relationships of* ***the total momentum of a system*** [during a collision with an] ***object outside itself*** *by examining what is known about smaller scale mechanisms within the system*. HS-PS2-2 and HS-PS2-3 **Systems and System Models** • Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. Students could construct an argument for how *models can be used to predict the behavior of* ***orbits*** [of] ***objects in the solar system****, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models* [for how] ***orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system***. HS-ESS1-4

Additional Connections to Nature of Science	**Scientific Investigations use a Variety of Methods (SEP):** • New technologies advance scientific knowledge. Students could construct an argument for how *new technologies* [have] *advanced scientific knowledge*, [including how] ***Kepler's laws describe common features of orbiting objects***. HS-ESS1-4 **Science is a Human Endeavor (CCC):** • Science and engineering are influenced by society and society is influenced by science and engineering. Students could construct an argument for how *engineering is influenced by society and society is influenced by engineering* [for issues related to] ***risk mitigation*** [during collisions]. HS-PS2-3

HS-PS2-1

Students who demonstrate understanding can:

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.** [Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled by a constant force.] [*Assessment Boundary: Assessment is limited to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

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Connections to Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- Theories and laws provide explanations in science.
- Laws are statements or descriptions of the relationships among observable phenomena.

Disciplinary Core Ideas

PS2.A: Forces and Motion

- Newton's second law accurately predicts changes in the motion of macroscopic objects.

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Observable features of the student performance by the end of the course:		
1	Organizing data	
	a	Students organize data that represent the net force on a macroscopic object, its mass (which is held constant), and its acceleration (e.g., via tables, graphs, charts, vector drawings).
2	Identifying relationships	
	a	Students use tools, technologies, and/or models to analyze the data and identify relationships within the datasets, including:
		i. A more massive object experiencing the same net force as a less massive object has a smaller acceleration, and a larger net force on a given object produces a correspondingly larger acceleration; and
		ii. The result of gravitation is a constant acceleration on macroscopic objects as evidenced by the fact that the ratio of net force to mass remains constant.
3	Interpreting data	
	a	Students use the analyzed data as evidence to describe* that the relationship between the observed quantities is accurately modeled across the range of data by the formula $a = F_{net}/m$ (e.g., double force yields double acceleration, etc.).
	b	Students use the data as empirical evidence to distinguish between causal and correlational relationships linking force, mass, and acceleration.
	c	Students express the relationship $F_{net}=ma$ in terms of causality, namely that a net force on an object causes the object to accelerate.

HS-PS2-2

Students who demonstrate understanding can:

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.** [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [*Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematics and Computational Thinking
Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical representations of phenomena to describe explanations.

Disciplinary Core Ideas

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.

Crosscutting Concepts

Systems and System Models

- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined.

Observable features of the student performance by the end of the course:		
1	Representation	
	a	Students clearly define the system of the two interacting objects that is represented mathematically, including boundaries and initial conditions.
	b	Students identify and describe* the momentum of each object in the system as the product of its mass and its velocity, $p = mv$ (p and v are restricted to one-dimensional vectors), using the mathematical representations.
	c	Students identify the claim, indicating that the total momentum of a system of two interacting objects is constant if there is no net force on the system.
2	Mathematical modeling	
	a	Students use the mathematical representations to model and describe* the physical interaction of the two objects in terms of the change in the momentum of each object as a result of the interaction.
	b	Students use the mathematical representations to model and describe* the total momentum of the system by calculating the vector sum of momenta of the two objects in the system.
3	Analysis	
	a	Students use the analysis of the motion of the objects before the interaction to identify a system with essentially no net force on it.
	b	Based on the analysis of the total momentum of the system, students support the claim that the momentum of the system is the same before and after the interaction between the objects in the system, so that momentum of the system is constant.
	c	Students identify that the analysis of the momentum of each object in the system indicates that any change in momentum of one object is balanced by a change in the momentum of the other object, so that the total momentum is constant.

HS-PS2-3

Students who demonstrate understanding can:

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.*** [Clarification Statement: Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute.] [*Assessment Boundary: Assessment is limited to qualitative evaluations and/or algebraic manipulations.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects.	**PS2.A: Forces and Motion** • 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. **ETS1.A: Defining and Delimiting an Engineering Problem** • Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. *(secondary)* **ETS1.C: Optimizing the Design Solution** • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed. *(secondary)*	**Cause and Effect** • Systems can be designed to cause a desired effect.

Observable features of the student performance by the end of the course:			
1	Using scientific knowledge to generate the design solution		
	a	Students design a device that minimizes the force on a macroscopic object during a collision. In the design, students:	
		i.	Incorporate the concept that for a given change in momentum, force in the direction of the change in momentum is decreased by increasing the time interval of the collision ($F\Delta t = m\Delta v$); and
		ii.	Explicitly make use of the principle above so that the device has the desired effect of reducing the net force applied to the object by extending the time the force is applied to the object during the collision.
	b	In the design plan, students describe* the scientific rationale for their choice of materials and for the structure of the device.	
2	Describing criteria and constraints, including quantification when appropriate		

	a	Students describe* and quantify (when appropriate) the criteria and constraints, along with the tradeoffs implicit in these design solutions. Examples of constraints to be considered are cost, mass, the maximum force applied to the object, and requirements set by society for widely used collision-mitigation devices (e.g., seatbelts, football helmets).
3	Evaluating potential solutions	
	a	Students systematically evaluate the proposed device design or design solution, including describing* the rationales for the design and comparing the design to the list of criteria and constraints.
	b	Students test and evaluate the device based on its ability to minimize the force on the test object during a collision. Students identify any unanticipated effects or design performance issues that the device exhibits.
4	Refining and/or optimizing the design solution	
	a	Students use the test results to improve the device performance by extending the impact time, reducing the device mass, and/or considering cost-benefit analysis.

HS-ESS1-2

Students who demonstrate understanding can:

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

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.

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Connections to Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.

Disciplinary Core Ideas

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.

PS4.B: Electromagnetic Radiation

- Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities. *(secondary)*

Crosscutting Concepts

Energy and Matter

- Energy cannot be created or destroyed–only moved between one place and another place, between objects and/or fields, or between systems.

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Connections to Engineering, Technology, and Applications of Science

Interdependence of Science, Engineering, and Technology

- Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise.

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Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future.
- Science assumes the universe is a vast single system in which basic laws are consistent.

Observable features of the student performance by the end of the course:		
1	Articulating the explanation of phenomena	
	a	Students construct an explanation that includes a description* of how astronomical evidence from numerous sources is used collectively to support the Big Bang theory, which states that the universe is expanding and that thus it was hotter and denser in the past, and that the entire visible universe emerged from a very tiny region and expanded.
2	Evidence	
	a	Students identify and describe* the evidence to construct the explanation, including:
		i. The composition (hydrogen, helium and heavier elements) of stars;
		ii. The hydrogen-helium ratio of stars and interstellar gases;
		iii. The redshift of the majority of galaxies and the redshift vs. distance relationship; and
		iv. The existence of cosmic background radiation.
	b	Students use a variety of valid and reliable sources for the evidence, which may include students' own investigations, theories, simulations, and peer review.
	c	Students describe* the source of the evidence and the technology used to obtain that evidence.
3	Reasoning	
	a	Students use reasoning to connect evidence, along with the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future, to construct the explanation for the early universe (the Big Bang theory). Students describe* the following chain of reasoning for their explanation:
		i. Redshifts indicate that an object is moving away from the observer, thus the observed redshift for most galaxies and the redshift vs. distance relationship is evidence that the universe is expanding.
		ii. The observed background cosmic radiation and the ratio of hydrogen to helium have been shown to be consistent with a universe that was very dense and hot a long time ago and that evolved through different stages as it expanded and cooled (e.g., the formation of nuclei from colliding protons and neutrons predicts the hydrogen-helium ratio [numbers not expected from students], later formation of atoms from nuclei plus electrons, background radiation was a relic from that time).
		iii. An expanding universe must have been smaller in the past and can be extrapolated back in time to a tiny size from which it expanded.

HS-ESS1-4

Students who demonstrate understanding can:

HS-ESS1-4. **Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.** [Clarification Statement: Emphasis is on Newtonian gravitational laws governing orbital motions, which apply to human-made satellites as well as planets and moons.] [*Assessment Boundary: Mathematical representations for the gravitational attraction of bodies and Kepler's laws of orbital motions should not deal with more than two bodies, nor involve calculus.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematical and Computational Thinking

Mathematical and computational thinking in 9–12 builds on K–8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical or computational representations of phenomena to describe explanations.

Disciplinary Core Ideas

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.

Crosscutting Concepts

Scale, Proportion, and Quantity

- Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).

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Connections to Engineering, Technology, and Applications of Science

Interdependence of Science, Engineering, and Technology

- Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise.

Observable features of the student performance by the end of the course:		
1	Representation	
	a	Students identify and describe* the following relevant components in the given mathematical or computational representations of orbital motion: the trajectories of orbiting bodies, including planets, moons, or human-made spacecraft; each of which depicts a revolving body's eccentricity e = f/d, where f is the distance between foci of an ellipse, and d is the ellipse's major axis length (Kepler's first law of planetary motion).
2	Mathematical or computational modeling	
	a	Students use the given mathematical or computational representations of orbital motion to depict that the square of a revolving body's period of revolution is proportional to the cube of its distance to a gravitational center ($T^2 \propto R^3$, where T is the orbital period and R is the semi-major axis of the orbit — Kepler's third law of planetary motion).
3	Analysis	
	a	Students use the given mathematical or computational representation of Kepler's second law of planetary motion (an orbiting body sweeps out equal areas in equal time) to predict the relationship between the distance between an orbiting body and its star, and the object's orbital velocity (i.e., that the closer an orbiting body is to a star, the larger its orbital velocity will be).

	b	Students use the given mathematical or computational representation of Kepler's third law of planetary motion ($T^2 \propto R^3$, where T is the orbital period and R is the semi-major axis of the orbit) to predict how either the orbital distance or orbital period changes given a change in the other variable.
	c	Students use Newton's law of gravitation plus his third law of motion to predict how the acceleration of a planet towards the sun varies with its distance from the sun, and to argue qualitatively about how this relates to the observed orbits.

HS-ETS1-1

Students who demonstrate understanding can:

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Asking Questions and Defining Problems Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. • Analyze complex real-world problems by specifying criteria and constraints for successful solutions.	**ETS1.A: Defining and Delimiting Engineering Problems** • Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. • Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.	- ***Connections to Engineering, Technology, and Applications of Science*** **Influence of Science, Engineering, and Technology on Society and the Natural World** • New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

Observable features of the student performance by the end of the course:			
1	Identifying the problem to be solved		
	a	Students analyze a major global problem. In their analysis, students:	
		i.	Describe* the challenge with a rationale for why it is a major global challenge;
		ii.	Describe*, qualitatively and quantitatively, the extent and depth of the problem and its major consequences to society and/or the natural world on both global and local scales if it remains unsolved; and
		iii.	Document background research on the problem from two or more sources, including research journals.
2	Defining the process or system boundaries, and the components of the process or system		
	a	In their analysis, students identify the physical system in which the problem is embedded, including the major elements and relationships in the system and boundaries so as to clarify what is and is not part of the problem.	
	b	In their analysis, students describe* societal needs and wants that are relative to the problem (e.g., for controlling CO_2 emissions, societal needs include the need for cheap energy).	
3	Defining the criteria and constraints		
	a	Students specify qualitative and quantitative criteria and constraints for acceptable solutions to the problem.	

HS-ETS1-3

Students who demonstrate understanding can:

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

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories.

- Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Disciplinary Core Ideas

ETS1.B: Developing Possible Solutions

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.

Crosscutting Concepts

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Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology on Society and the Natural World

- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

Observable features of the student performance by the end of the course:			
1	Evaluating potential solutions		
	a	In their evaluation of a complex real-world problem, students:	
		i.	Generate a list of three or more realistic criteria and two or more constraints, including such relevant factors as cost, safety, reliability, and aesthetics that specifies an acceptable solution to a complex real-world problem;
		ii.	Assign priorities for each criterion and constraint that allows for a logical and systematic evaluation of alternative solution proposals;
		iii.	Analyze (quantitatively where appropriate) and describe* the strengths and weaknesses of the solution with respect to each criterion and constraint, as well as social and cultural acceptability and environmental impacts;
		iv.	Describe* possible barriers to implementing each solution, such as cultural, economic, or other sources of resistance to potential solutions; and
		v.	Provide an evidence-based decision of which solution is optimum, based on prioritized criteria, analysis of the strengths and weaknesses (costs and benefits) of each solution, and barriers to be overcome.
2	Refining and/or optimizing the design solution		
	a	In their evaluation, students describe* which parts of the complex real-world problem may remain even if the proposed solution is implemented.	