Physics, Unit 1

Forces and Motion

Overview

Unit abstract

In this unit of study, students will develop an understanding of ideas related to why some objects keep moving and some objects fall to the ground. Students will build an understanding of forces and Newton's second law. They also develop an understanding that the total momentum of a system of objects is conserved when there is no net force on the system. Students are able to apply science and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision. The crosscutting concepts of patterns, cause and effect, and systems and systems models are called out as organizing concepts for these disciplinary core ideas. In the PS2 performance expectations, students are expected to demonstrate proficiency in planning and conducting investigations, analyzing data and using math to support claims, and applying scientific ideas to solve design problems and to use these practices to demonstrate understanding of the core ideas.

Essential question

- How can one explain and predict interactions between objects and within systems of objects?

Written Curriculum

Next Generation Science Standards*

HS. Forces and Interactions

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 expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
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. (HS-PS2-1) ------------------------------------- ***Connections to Nature of Science*** **Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** ▪ Theories and laws provide explanations in science. (HS-PS2-1) ▪ Laws are statements or descriptions of the relationships among observable phenomena. (HS-PS2-1)	**PS2.A: Forces and Motion** ▪ Newton's second law accurately predicts changes in the motion of macroscopic objects. (HS-PS2-1)	**Cause and Effect** ▪ Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS2-1)

Connections to other DCIs in this grade-band: **HS.PS3.C** (HS-PS2-1); **HS.ESS1.A** (HS-PS2-1); **HS.ESS1.C** (HS-PS2-1); **HS.ESS2.C** (HS-PS2-1)

Articulation to DCIs across grade-bands: **MS.PS2.A** (HS-PS2-1); **MS.PS3.C** (HS-PS2-1)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *(HS-PS2-1)*
RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-PS2-1)
WHST.9-12.9	Draw evidence from informational texts to support analysis, reflection, and research. *(HS-PS2-1)*

Mathematics –

MP.2	Reason abstractly and quantitatively. (HS-PS2-1)
MP.4	Model with mathematics. (HS-PS2-1)
HSN-Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS2-1)
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. *(HS-PS2-1)*
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS2-1)
HSA-SSE.A.1	Interpret expressions that represent a quantity in terms of its context. (HS-PS2-1)
HSA-SSE.B.3	Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression. (HS-PS2-1)
HSA-CED.A.1	Create equations and inequalities in one variable and use them to solve problems. (HS-PS2-1)
HSA-CED.A.2	Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. *(HS-PS2-1)*
HSA-CED.A.4	Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. *(HS-PS2-1)*
HSF-IF.C.7	Graph functions expressed symbolically and show key features of the graph, by in hand in simple cases and using technology for more complicated cases. *(HS-PS2-1)*
HSS-ID.A.1	Represent data with plots on the real number line (dot plots, histograms, and box plots). *(HS-PS2-1)*

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HS. Forces and Interactions

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 expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
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. (HS-PS2-2)	**PS2.A: Forces and Motion** ▪ Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. (HS-PS2-2) ▪ 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)	**Systems and System Models** ▪ When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. (HS-PS2-2)

Connections to other DCIs in this grade-band: **HS.ESS1.A** (HS-PS2-2); **HS.ESS1.C** (HS-PS2-2)

Articulation to DCIs across grade-bands: **MS.PS2.A** (HS-PS2-2); **MS.PS3.C** (HS-PS2-2)

Common Core State Standards Connections:

Mathematics –

MP.2	Reason abstractly and quantitatively. (HS-PS2-2)
MP.4	Model with mathematics. (HS-PS2-2)
HSN-Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS2-2)
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. *(HS-PS2-2)*
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS2-2)
HSA-CED.A.1	Create equations and inequalities in one variable and use them to solve problems. (HS-PS2-2)
HSA-CED.A.2	Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. *(HS-PS2-2)*
HSA-CED.A.4	Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. *(HS-PS2-2)*

HS. Forces and Interactions		
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 expectations above were developed using the following elements from the NRC document *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. (HS-PS2-3)	**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. (HS-PS2-3) **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. *(secondary to HS-PS2-3)* **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 (trade-offs) may be needed. *(secondary to HS-PS2-3)*	**Cause and Effect** ▪ Systems can be designed to cause a desired effect. (HS-PS2-3)
Connections to other DCIs in this grade-band: N/A		
Articulation to DCIs across grade-bands: **MS.PS2.A** (HS-PS2-3); **MS.PS3.C** (HS-PS2-3)		
Common Core State Standards Connections: *ELA/Literacy –* **WHST.9-12.7** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS2-3)		

HS. Engineering Design

Students who demonstrate understanding can:

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

The performance expectations above were developed using the following elements from the NRC document *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. ▪ Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-2)	**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 (trade-offs) may be needed. (HS-ETS1-2)	N/A

Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include:
Physical Science: HS-PS2-3, HS-PS3-3
Connections to HS-ETS1.B: Designing Solutions to Engineering Problems include:
Earth and Space Science: HS-ESS3-2, HS-ESS3-4, **Life Science:** HS-LS2-7, HS-LS4-6
Connections to HS-ETS1.C: Optimizing the Design Solution include:
Physical Science: HS-PS1-6, HS-PS2-3

Articulation of DCIs across grade-bands: **MS.ETS1.A** (HS-ETS1-2); **MS.ETS1.B** (HS-ETS1-2); **MS.ETS1.C** (HS-ETS1-2)

Common Core State Standards Connections:
Mathematics –
MP.4 Model with mathematics. (HS-ETS1-2)

HS. Engineering Design		
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 expectations above were developed using the following elements from the NRC document *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. ▪ Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)	**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. (HS-ETS1-3)	***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. (HS-ETS1-3)
Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include: **Physical Science:** HS-PS2-3, HS-PS3-3 *Connections to HS-ETS1.B: Designing Solutions to Engineering Problems include:* **Earth and Space Science:** HS-ESS3-2, HS-ESS3-4, **Life Science:** HS-LS2-7, HS-LS4-6 *Connections to HS-ETS1.C: Optimizing the Design Solution include:* **Physical Science:** HS-PS1-6, HS-PS2-3		
Articulation of DCIs across grade-bands: **MS.ETS1.A** (HS-ETS1-3); **MS.ETS1.B** (HS-ETS1-3)		
Common Core State Standards Connections: *ELA/Literacy –* **RST.11-12.7** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. *(HS-ETS1-3)* **RST.11-12.8** Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-ETS1-3) **RST.11-12.9** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. *(HS-ETS1-3)* *Mathematics –* **MP.2** Reason abstractly and quantitatively. *(HS-ETS1-3)* **MP.4** Model with mathematics.(HS-ETS1-3)		

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of Grade 8, students know that:

Physical science

- 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.
- When two objects interact, each one exerts a force on the other that can cause energy to be transferred from one object to the other.

Progression of current learning

Driving question 1
What is mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration?

Concepts

- Theories and laws provide explanations in science.
- Laws are statements or descriptions of the relationships among observable phenomena.
- Empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects.
- Newton’s second law accurately predicts changes in the motion of macroscopic objects.

Practices

- Analyze data using tools, technologies, and/or models 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.
- Analyze data using one-dimensional motion at nonrelativistic speeds 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.

- Use empirical evidence 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.

Driving question 2
How is the total momentum of a system of objects conserved?

Concepts

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

Practices

- 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.
- Use mathematical representations of the quantitative conservation of momentum and the qualitative meaning of this principle in systems of two macroscopic bodies moving in one dimension.
- Describe the boundaries and initial conditions of a system of two macroscopic bodies moving in one dimension.

Driving question 3
How can the force on a macroscopic object during a collision be minimized?

Concepts

- 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.
- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and the criteria and constraints should be quantified to the extent possible and stated in such a way that one can determine whether a given design meets them.
- Criteria may need to be broken down into simpler ones that can be approached

Practices

- Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
- Apply scientific ideas to solve a design problem for a device that minimizes the force on a macroscopic object during a collision, taking into account possible unanticipated effects.
- Use qualitative evaluations and /or algebraic manipulations to design and refine a device that minimizes the force on a macroscopic object during a collision.

systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.

- 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.
- 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.
- Systems can be designed to cause a desired effect.

Integration of content, practices, and crosscutting concepts

This unit begins with a focus on forces, and students need to have a foundational understanding of the kinematic equations in order to understand acceleration and, subsequently, Newton's second law. Emphasis in understanding Newton's second law is on data collection and analysis to support mathematical relationships.

Students will require deeper prerequisite knowledge in order to deal with the acceleration portion of $F = ma$. Students should be taught how to calculate displacement, velocity, and acceleration using the following equations: $d = v_i t + \frac{1}{2}at^2$, $v_f = v_i + at^2$, $v_f^2 = v_i^2 + 2ad$, and $d = \frac{v_i + v_f}{2} * t$. Students should use experimental data to confirm the mathematical relationships among displacement, time, velocity, and acceleration. Students might also use accelerometers in order to measure acceleration. Provide opportunities to measure, record, and analyze acceleration values from observed laboratory data in order to confirm Newton's second law. This can be done using accelerometers to generate data that will allow students to determine the mathematical relationship $F = ma$ or using the previously developed equation for acceleration.

Students should construct and analyze models with regard to force, mass, and acceleration. These models may include drawn diagrams, mathematical models, graphs, and laboratory equipment. For example, a lab car with a lighter mass and a lab car with a heavier mass are launched with the same initial force. The acceleration of each car is measured directly or calculated. Students should be able to deduce through calculations and graphing that changing the mass while keeping the force constant results in the same acceleration. Students must be able to use the models they construct to make valid and reliable scientific claims using Newton's second law, and they must be able to predict changes in the motion of objects.

Students will need an understanding of the cause-and-effect relationships among force, mass, and acceleration in order to predict the motion of a body. For example, if a physics car's mass is increased, then the effect is that it does not accelerate as quickly when launched by a rubber band. The lesser acceleration is a result of the increased mass while the rubber band provides a constant force. Students will need to perform calculations using $F = ma$, including in free-fall situations, in order to demonstrate the uniform acceleration of the force of gravity.

Students should be given opportunities to graph data relating to $F = ma$. Graphs should have appropriate labels, units, and scale. Students must be able to recognize and interpret trends in data. For example, students could calculate the slope of a trend line on a velocity–time or force–mass graph and interpret its meaning. It is important to note that assessment is limited to motion in one dimension.

Students should be able to discuss, explain, interpret, and apply Newton's first and second laws. In the second half of this unit, Newton's third law will be further developed with regard to momentum. Students will also demonstrate that momentum is conserved when the net force is zero.

As the unit progresses to a focus on momentum, Newton's third law should be introduced and relationships to the Law of Conservation of Momentum should be outlined. For example, put two physics cars with spring triggers against each other and depress the mechanism. Observe how the cars behave. Which goes farther, which goes faster, and so on? Try this with equal masses and various different masses and ask students to discuss the implications regarding force, mass, and acceleration. This naturally leads to Newton's third law regarding how $F_{a\ on\ b} = F_{b\ on\ a}$. With different masses, this identical force in opposite directions results in proportionally different accelerations. Other examples may include fan cars, marbles of different masses, sumo wrestlers, worksheets, egg drops, egg drops under bleachers with different helmets, force meters, bungee jumping, diving, forces, spring constants, bumpers, seat belts, foam, etc. It is important to note that assessment is limited to two interacting objects in one dimension.

Students should understand what a system is, how it can change, how to define its boundaries, what is meant by initial conditions, and how the system interacts with other systems. Students must be able to define the boundaries and initial conditions of a closed system.

Students will need to use and manipulate various equations relating to conservation of momentum. These equations include $F = ma,\ p = mv,\ \Delta p = Ft,$ and total initial momentum of a system = total final momentum of a system. Students should already have a good understanding of $F = ma$ from the first part of this unit. The same spring cars used to introduce the second half of the lesson can be analyzed in terms of $p = mv$. Given $p = mv$, students should be able to derive $\Delta p = Ft$ by substituting $F = ma$ and $\Delta a = \frac{\Delta v}{\Delta t}$.

To develop an understanding of the equations above, students should construct and analyze models with regard to momentum, mass, velocity, force, and time. These models may include drawn diagrams, mathematical models, graphs, and laboratory equipment. Students should be able to use these models to make valid and reliable scientific claims and predict changes in the motion of objects with regard to momentum, mass, velocity, and force. These predictions and claims must be both qualitative and quantitative. Students must understand that by increasing the time of a collision, they are decreasing the force of the collision.

In working to design, evaluate, and refine a device to minimize force, students could design and perform a crash-prevention and force-reduction investigation. For example, students might pad an egg sufficiently to prevent it from breaking when dropped. This investigation may include use of a toilet paper tube, tissue paper, bubble wrap, foam rubber, shredded paper, zip-top bags, parachutes, plastic bags, boxes, cartons, etc. The drop may be attempted from varying heights. Be sure to engage students in discussion of the implications of momentum, force, time, and impulse. What were students' design ideas and methodology? What designs did students decide on and why? What did they think was a good idea and why? If they were to do it again, what would they change? Later in the year, you can go back to this activity, have students carefully consider analyses, and then have them redo the experiment.

Students should analyze and compare data from labs they have performed to determine consistency, accuracy, and trends. For example, trends may include relationships among force, mass, and acceleration. Trends may be linear or exponential. Students must also be able to account for possible unanticipated effects. Students should also be able to evaluate the results of an experiment to determine relationships among variables and ways to improve upon their results in future trials. Students will need to cite experimental evidence from their data to make and support valid, reliable scientific claims regarding Newton's second law and the Law of Conservation of Momentum. Students could construct and analyze models including drawn diagrams, mathematical models, graphs, and laboratory equipment to represent relationships among force, mass, acceleration, and momentum.

Students might also generate explanations for observed phenomena and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. Finally, students should design and perform a crash-prevention and force-reduction exercise or experiment. An example of such an experiment is padding an egg sufficiently to prevent it from breaking when dropped, which supports the law of Conservation of Momentum.

Integration of engineering

In this unit, the engineering performance expectation identifies HS-ETS1-2 and HS-ETS1-3 as connections. To meet this requirement of the standard, students will design a solution to a complex real-world problem by breaking it into smaller, more manageable problems. They will also evaluate their solution, considering a range of constraints such as cost, safety, reliability, and aesthetics. Consideration should also be paid to social, cultural, and environmental impacts.

Integration of mathematics English language arts/literacy

Mathematics

- Represent 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 symbolically and manipulate the representative symbols. Make sense of quantities and relationships among net force on a macroscopic object, its mass, and its acceleration.
- Use a mathematical model to describe how Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. Identify important quantities representing the net force on a macroscopic object, its mass, and its acceleration and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Use units as a way to understand how Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. Choose and interpret units consistently in Newton's second law of motion, and choose and interpret the scale and origin in graphs and data displays representing the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
- Define appropriate quantities for the purpose of descriptive modeling of Newton's second law of motion.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the net force on a macroscopic object, its mass, and its acceleration.
- Interpret expressions that represent the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration in terms of its context.
- Choose and produce an equivalent form of Newton's second law to reveal and explain properties of the quantity represented by the expression.
- Create equations and inequalities in one variable and use them to solve for the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
- Create equations in two or more variables to represent relationships among the net force on a macroscopic object, its mass, and its acceleration; graph equations on coordinate axes with labels and scales.

- Rearrange Newton's second law to highlight a quantity of interest, using the same reasoning used in solving equations.
- Graph the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration and show key features of the graph, by hand in simple cases and using technology for more complicated cases.
- Represent data of the net force on a macroscopic object, its mass, and its acceleration with plots on the real number line (dot plots, histograms, and box plots).
- Use symbols to represent the claim that the total momentum of a system of objects is conserved when there is no net force on the system and manipulate the representative symbols. Make sense of quantities and relationships between the total momentum of a system of objects and the net force on the system.
- Use a mathematical model to describe how the total momentum of a system of objects is conserved when there is no net force on the system. Identify important quantities representing the total momentum of a system of objects and the net force on the system and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Use units as a way to understand the conservation of the total momentum of a system of objects when there is no net force on the system. Choose and interpret units consistently in formulas representing the total momentum of a system of objects, and choose and interpret the scale and origin in graphs and data displays representing the conservation of the total momentum of a system of objects when there is no net force on the system.
- Define appropriate quantities for the purpose of descriptive modeling of the conservation of the total momentum of a system of objects when there is no net force on the system.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the conservation of the total momentum of a system of objects and the net force on the system.
- Create equations and inequalities in one variable and use them to determine that the total momentum of a system of objects is conserved when there is no net force on the system.
- Create equations in two or more variables to represent the relationship between conservation of the total momentum of a system of objects and the net force on the system.
- Rearrange formulas representing the conservation of momentum of a system of objects and the net force on the system to highlight a quantity of interest, using the same reasoning used in solving equations.
- Use symbols to represent the force on a macroscopic object during a collision and manipulate the representing symbols. Make sense of quantities and relationships between different device designs and the force on a macroscopic object during a collision.
- Use a mathematical model to describe how different device designs affect the force on a macroscopic object during a collision. Identify important quantities representing the force on a macroscopic object during a collision in different device designs to minimize force and map relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model (design) if it has not served its purpose.

English language arts/literacy

- Cite specific textual evidence 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.
- Integrate and evaluate multiple sources of information presented in diverse formats and media in order 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.
- Draw evidence from informational texts 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.
- Conduct short as well as more sustained research projects to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
- Integrate and evaluate multiple sources of information presented in diverse formats and media in order to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
- Evaluate the hypotheses, data, analysis, and conclusions in a scientific or technical text in order to refine a device that minimizes the force on a macroscopic object during a collision.
- Analyze multiple sources to inform design decisions.

Connected learning

Connections to disciplinary core ideas in other high school courses are as follows:

Physical science

- When two objects interacting through a field change relative position, the energy stored in the field is changed.

Earth and space science

- 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.
- The Big Bang theory is supported by observations of distant galaxies receding from our own, by measured composition of stars and nonstellar gases, and by 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.
- Continental rocks, which can be more than 4 billion years old, are generally much older than the rocks of the ocean floor, which are less than 200 million years old.
- 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.

- 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. Water's physical and chemical properties include its 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.

Number of Instructional Days

Recommended number of instructional days: 25 (1 day = approximately 50 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

Additional NGSS Resources

The following resources were consulted during the writing of this unit:

- Next Generation Science Standards Appendices I, L, and M
- *A Framework for K–12 Science Education*
- Common Core State Standards Appendices (Mathematics and English Language Arts/Literacy)