Unit 3 Forces

Content Area: **Science**
Course(s):
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Topic Outline

Newton's First Law of Motion

- Newton's First Law / Inertia and Mass
- States of Motion / Balanced and Unbalanced Forces

Force and Its Representation

- The Meaning of Force / Types of Forces
- Drawing Free-Body Diagrams / Determining the Net Force

Newton's Second Law of Motion

- Newton's Second Law / The Big Misconception / Finding Acceleration
- Finding Individual Forces / Free Fall and Air Resistance

Newton's Third Law of Motion

- Newton's Third Law / Identifying Action and Reaction Force Pairs

Enduring Understandings

Big things they want to know.

- Ideas can be represented in numerous ways such as graphs, mathematical formulas, free body diagrams, bar charts, etc.
- Scientific laws can be used to make predictions about outcomes.
- Problems can be solved in many different ways and using many different formulas/topics.
- Mathematical representations can be derived using graphs and previous mathematical representations.
- Defining the system (including both the initial and final conditions of the system) is important in solving and understanding problems.
- There are mathematical relationships expressed in physics equations, such as inverse, direct, or exponential.

Essential Questions

What should they be able to answer at the end of course.

- What causes objects to change speed or direction?
- What is the difference between mass and weight?
- What is the mathematical relationship between force, mass and acceleration?
- What forces are at work on an object in free-fall?
- What phenomena can be explained by the strong nuclear, weak nuclear, electromagnetic and gravitational forces?

Student Learning Objectives (PE, SEP, DCI, CCC) & Aligned Standards

Standards need to be linked. Hit associated standards NH Student Learning Standards

(+ Honors Only Skills)

- An in depth look at adding and subtracting vectors will be discussed in the honors classes.
- Students at the honors level will derive equations with less support than the students at the CP level.
- The honors level will go into more detail in terms of the problems they are given, the force diagrams they draw, the graphs they analyze, etc.
- The honors level may also discuss projectile motion.

Given a graph of position or velocity as a function of time, recognize in what time intervals the position, velocity and acceleration of an object are positive, negative, or zero and sketch a graph of each quantity as a function of time. *[Clarification Statement: Students should be able to accurately move from one representation of motion to another.]* (PS2.A)

Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. (PS2.A)

Understand and apply the relationship between the net force exerted on an object, its inertial mass, and its acceleration to a variety of situations. (PS2.A)

Performance Expectations

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-PS2-1)

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-PS2-2)

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-PS2-3)

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

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. (HS-ETS1-3)

Science and Engineering Practices

Analyzing and Interpreting 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)

Using Mathematics and Computational Thinking

- Use mathematical representations of phenomena to describe explanations. (HS-PS2-2)

Constructing Explanations and Designing Solutions

- Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects. (HSPS2-3)
- 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)
- 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)

Disciplinary Core Ideas

PS2.A: Forces and Motion

- Newton's second law accurately predicts changes in the motion of macroscopic objects. (HS-PS2-1)
- 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)

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-PS23)

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 to (HS-PS2-3)

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)

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS21)
- Systems can be designed to cause a desired effect. (HS-PS2-3)

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 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 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)

	Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.
SEP.1.a	Ask questions
CCC.2.1	students understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They also propose causal relationships by examining what is known about smaller scale mechanisms within the system. They recognize changes in systems may have various causes that may not have equal effects.
SEP.1.a.3	to determine relationships, including quantitative relationships, between independent and dependent variables.
SEP.1.b	Evaluate a question to determine if it is testable and relevant.
SEP.1.d	Ask and/or evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design.
	Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.
SEP.2.b	Design a test of a model to ascertain its reliability.
SEP.2.c	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.
SEP.2.f	Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.
SEP.3.b	Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.
SEP.3.c	Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts.
SEP.3.d	Select appropriate tools to collect, record, analyze, and evaluate data.
SEP.3.f	Manipulate variables and collect data about a complex model of a proposed process or

	system to identify failure points or improve performance relative to criteria for success or other variables.
SEP.4.b	Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible.
SEP.4.c	Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data.
SEP.4.d	Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations.
SEP.4.f	Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.
SEP.5.b	Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.
SEP.5.c	Apply techniques of algebra and functions to represent and solve scientific and engineering problems.
SEP.5.e	Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m^3, acre-feet, etc.).
SEP.6.a	Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.
SEP.6.c	Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.
SEP.6.e	Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade-off considerations.
SEP.7.a	Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues.
SEP.7.b	Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.
SEP.7.c	Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence, challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining additional information required to resolve contradictions.
SEP.7.d	Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.
SEP.7.e	Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.
SEP.7.f	Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and/or logical arguments regarding relevant factors (e.g., economic, societal, environmental, ethical considerations).
SEP.8.b	Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem.
SCI.9-12.1.2	Classifications or explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced; thus requiring improved investigations and experiments.
SCI.9-12.1.4	Mathematical representations are needed to identify some patterns.
SCI.9-12.1.5	Empirical evidence is needed to identify patterns.

SCI.9-12.2.3	Systems can be designed to cause a desired effect.
SCI.9-12.2.4	Changes in systems may have various causes that may not have equal effects.
SCI.9-12.3.2	Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly.
SCI.9-12.3.3	Patterns observable at one scale may not be observable or exist at other scales.
SCI.9-12.3.5	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).
SCI.9-12.6.2	The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials.
SCI.9-12.7.2	Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.
SCI.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.
SCI.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.
SCI.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.
SCI.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.
SCI.HS-PS2-6	Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

Concepts & Formative Assessment

Part A: How do they know how long the yellow light should be on before it turns red? (*traffic light*)

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.

Formative Assessment

Students who understand the concepts are able to:

- 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.

Part B: How can a piece of space debris the size of a pencil eraser destroy the International Space Station?

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.

Formative Assessment

Students who understand the concepts are able to:

- 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.

Part C: Red light cameras were placed in intersections to reduce the number of collisions caused by cars running red lights. Many people thought that they were unfair and demanded that they be removed. As an expert on the physics of moving bodies, you are challenged to engineer traffic signals to proactively reduce the number of people entering an intersection after the light turns red. The cost of the redesign must not exceed 10% of the current cost of current traffic signals or the energy needed to operate them.

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 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.

Formative Assessment

Students who understand the concepts are able to:

- 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.

Resources

Forces in One Dimension: Explore the forces at work when you try to push a filing cabinet. Create an applied force and see the resulting friction force and total force acting on the cabinet. Charts show the forces, position, velocity, and acceleration vs. time. View a Free Body Diagram of all the forces (including gravitational and normal forces).

Forces and Motion: Explore the forces at work when you try to push a filing cabinet. Create an applied force and see the resulting friction force and total force acting on the cabinet. Charts show the forces, position, velocity, and acceleration vs. time. View a Free Body Diagram of all the forces (including gravitational and normal forces).

Parachute and Terminal Velocity: How does an object's speed change as it falls through the atmosphere? When first learning about how objects fall, usually just one force—gravity—is considered. Such a simplification only accurately describes falling motion in a vacuum. This model of a parachute carrying a load incorporates a second force—air resistance—and allows experimentation with two variables that affect its speed: the size of the parachute and the mass of its load. This model graphs both the parachute's height above the Earth's surface and its speed after it is released. Motion continues until a constant speed is achieved, the terminal velocity.

Physics Teaching Technology Resource (http://paer.rutgers.edu/pt3/)
Videos to help students develop ideas using the scientific process, test ideas, and disprove ideas.

The Physics Classroom (http://www.physicsclassroom.com/class)
Tutorials and resources for all physics topics. For this unit, there are helpful graphing, motion diagram, and free body diagram activities.

The Science Classroom

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: 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.

Uniform acceleration equations

$$d = v_i t + {}^1/_2 a t^2 \qquad v_f^2 = v_i^2 + 2ad \qquad v_f^2 = v_i^2 + 2ad \qquad d = {}^1/_2(v_f + v_i)t$$

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 $F_{\text{a on b}} = F_{\text{b on a}}$ 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 $\Delta a = \Delta v / \Delta t$.

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-

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.

Connecting with English Language Arts Literacy and Mathematics

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.

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.

Modifications

Teacher Note: Teachers identify the modifications that they will use in the unit. The unneeded modifications can then be deleted from the list.

- Restructure lesson using UDL principals (http://www.cast.org/our-work/about-udl.html#.VXmoXcfD_UA)
- Structure lessons around questions that are authentic, relate to students' interests, social/family background and knowledge of their community.
- Provide students with multiple choices for how they can represent their understandings (e.g. multisensory techniques-auditory/visual aids; pictures, illustrations, graphs, charts, data tables, multimedia, modeling).
- Provide opportunities for students to connect with people of similar backgrounds (e.g. conversations via digital tool such as SKYPE, experts from the community helping with a project, journal articles, and biographies).
- Provide multiple grouping opportunities for students to share their ideas and to encourage work among various backgrounds and cultures (e.g. multiple representation and multimodal experiences).
- Engage students with a variety of Science and Engineering practices to provide students with multiple entry points and multiple ways to demonstrate their understandings.

- Use project-based science learning to connect science with observable phenomena.
- Structure the learning around explaining or solving a social or community-based issue.
- Provide ELL students with multiple literacy strategies.
- Collaborate with after-school programs or clubs to extend learning opportunities.

Research on Student Learning

Students tend to think of force as a property of an object ("an object has force," or "force is within an object") rather than as a relation between objects. In addition, students tend to distinguish between active objects and objects that support or block or otherwise act passively. Students tend to call the active actions "force" but do not consider passive actions as "forces". Teaching students to integrate the concept of passive support into the broader concept of force is a challenging task even at the high-school level.

Students believe constant speed needs some cause to sustain it. In addition, students believe that the amount of motion is proportional to the amount of force; that if a body is not moving, there is no force acting on it; and that if a body is moving there is a force acting on it in the direction of the motion. Students also believe that objects resist acceleration from the state of rest because of friction -- that is, they confound inertia with friction. Students tend to hold on to these ideas even after instruction in high-school or college physics. [6] Specially designed instruction does help high-school students change their ideas.

Research has shown less success in changing middle-school students' ideas about force and motion. Nevertheless, some research indicates that middle-school students can start understanding the effect of constant forces to speed up, slow down, or change the direction of motion of an object. This research also suggests it is possible to change middle-school students' belief that a force always acts in the direction of motion.

Students have difficulty appreciating that all interactions involve equal forces acting in opposite directions on the separate, interacting bodies. Instead they believe that "active" objects (like hands) can exert forces whereas "passive" objects (like tables) cannot. Alternatively, students may believe that the object with more of some obvious property will exert a greater force. Teaching high-school students to seek consistent explanations for the "at rest" condition of an object can lead them to appreciate that both "active" and "passive" objects exert forces. Showing high-school students that apparently rigid or supporting objects actually deform might also lead them to appreciate that both "active" and "passive" objects exert forces (NSDL, 2015).

Prior Learning

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.

Connections to Other Courses

Physical Science-

- 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.

Earth and space sciences-

- 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.

References

Adapted from the New Jesery NGSS Science Model Curriclum

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Connections to NJSLS

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.11-12.1**
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) **RST.11-12.7**
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.11-12.8**
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) **RST.11-12.9**
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-ETS1-3) **WHST.11-12.7**
Draw evidence from informational texts to support analysis, reflection, and research. (HS-PS2-1) **WHST.11-12.9**

MATHEMATICS

Reason abstractly and quantitatively. (HS-PS2-1),(HS-PS2-2),(HS-ETS1-1),(HS-ETS1-3),(HS-ETS1-4) **MP.2**

Model with mathematics. (HS-PS2-1),(HS-PS2-2),(HS-ETS1-2),(HS-ETS1-3),(HS-ETS1-4) **MP.4**

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),(HS-PS2-2) **HSN.Q.A.1**

Define appropriate quantities for the purpose of descriptive modeling. (HS-PS2-1),(HS-PS2-2) **HSN.Q.A.2**

Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS2-1),(HS-PS2-2) **HSN.Q.A.3**

Interpret expressions that represent a quantity in terms of its context. (HS-PS2-1) **HSA.SSE.A.1**

Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression. **HSA.SSE.B.3** (HS-PS2-1)

Create equations and inequalities in one variable and use them to solve problems. (HS-PS2-1),(HS-PS2-2) **HSA.CED.A.1**

Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. (HS-PS2-1),(HS-PS2-2) **HSA.CED.A.2**

Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. (HS-PS2-1),(HS-PS2-2)

HSA.CED.A.4

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) **HSF-IF.C.7**

Represent data with plots on the real number line (dot plots, histograms, and box plots). (HS-PS2-1) **HSS-IS.A.1**