## *Force and Motion*

# Car and Ramp

link™

CPO Science

Real Investigations in
Science and Engineering

# Overview Chart for Investigations–Car and Ramp

| | Investigation | Key Question | Summary | Learning Goals | Vocabulary |
|---|---|---|---|---|---|
| A1 | **Systems, Experiments, and Variables**<br>Pages 1-6<br>50 minutes | Why do we control variables in an experiment? | Students will identify the variables that affect the speed of a car rolling down a ramp, design an experiment where there are several variables to be controlled, and recognize a poorly designed experiment where more than one variable has been changed. | • Identify variables in an experiment.<br>• Recognize the importance of controlling variables.<br>• Design a controlled experiment. | control variable<br>dependent variable<br>experiment<br>hypothesis<br>independent variable<br>scientific method<br>system<br>variable |
| A2 | **Speed**<br>Pages 7-12<br>50 minutes | What is speed and how is it measured? | Students will use the CPO Timer, photogates, and Car and Ramp to calculate speed in units of inches per second, feet per second, and centimeters per second. They evaluate the effect of changing different variables on speed and develop confidence with calculations of speed. Students will design three experiments involving the variables that affect the speed of the car on the ramp. | • Define and calculate speed.<br>• Express speed with the proper units.<br>• Recognize the variables that affect the speed of a car going down a ramp. | average speed<br>constant speed<br>position<br>speed<br>velocity |
| A3 | **Graphs of Motion**<br>Pages 13-20<br>100 minutes | How can you graph the motion of an object rolling down a hill? | Students learn how to measure and graph motion. They use photogates to measure the time it takes the car to reach different points on the track, and they use the data to make position vs. time and speed vs. time graphs. Graphing allows students to see the relationship between the manipulated and responding variables. | • Use position and time data to construct a position vs. time graph.<br>• Calculate a car's average speed and speed at various points as it rolls down a track.<br>• Construct a graph of speed versus time. | acceleration<br>average speed<br>instantaneous speed<br>rise<br>run<br>slope |
| A4 | **Measuring Forces**<br>Pages 21-26<br>50 minutes | How can a ramp be used to change the force needed to move an object? | In this investigation, students learn how to accurately measure forces with spring scales. They measure the force needed to pull a car up a ramp and determine how that force depends on the slope of the ramp. | • Identify units for measuring force.<br>• Accurately measure forces with a spring scale.<br>• Recognize that the force needed to move an object up a hill depends on the hill's steepness. | force<br>newton<br>pound<br>vector<br>weight |
| A5 | **Force and Motion**<br>Pages 27-32<br>50 minutes | How does force affect motion? | Students study the relationship between force and acceleration that is explained by Newton's first law. Students do not directly measure the acceleration of the car, but instead look at the amount that the car speeds up while rolling down the ramp. Students observe that the car speeds up more when the ramp is steeper. | • Identify the difference between balanced and unbalanced forces.<br>• Determine the speed of a car at the bottom of a ramp.<br>• Describe the relationship between the force acting on a car and the amount it speeds up when rolling down a ramp. | acceleration<br>Newton's first law<br>unbalanced force |

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| **A6** | **Newton's Second Law**<br>Pages 33-38<br>50 minutes | How are force, mass, and acceleration related? | Students will gain a conceptual understanding of the relationship between force, mass, and acceleration that is explained by Newton's second law. They first observe how changing an object's mass affects its acceleration while force is kept constant. They then keep the mass constant but vary the force. The results will be used to explain why Newton's second law is the equation a = F/m. | • Identify the relationship between mass and acceleration (when force is kept constant).<br>• Identify the relationship between force and acceleration (when mass is kept constant).<br>• Use the results of the investigation to explain why Newton's second law is the equation a = F/m. | acceleration<br>directly proportional<br>inversely proportional<br>mass<br>newton<br>Newton's second law |
| **A7** | **Gravity**<br>Pages 39-44<br>50 minutes | Does gravity cause cars of different weights to travel at different speeds as they roll down a ramp? | In this investigation, students learn that weight has little effect on the speed at which the car moves down the ramp. As weights are added to the car, the speed calculated at a specific point on the ramp changes only slightly. Graphing speed as a function of the car weight confirms this. | • Determine the speed of a car rolling down a ramp when different amounts of weight are added.<br>• Construct a graph of speed versus the number of weights added to the car.<br>• Recognize that weight does not have a significant effect on the speed of a car rolling down a ramp. | force of gravity (or gravitational force)<br>Newton's law of universal gravitation<br>Newton's second law<br>weight |
| **A8** | **Friction**<br>Pages 45-50<br>50 minutes | How does friction affect the motion of a car on a ramp? | Students will create a hypothesis about how adding air friction to the car affects its speed as it moves down the ramp. They will then collect data to determine whether their hypothesis was correct. | • Use photogates to determine the speed of a car as it rolls down a ramp.<br>• Increase the air friction acting on the car.<br>• Compare the speed of the car with and without the added friction. | air friction<br>friction<br>rolling friction<br>static friction<br>sliding friction<br>viscous friction |
| **B1** | **Systems and Models: What Is Speed?**<br>Pages 51-58<br>50 minutes | How can we use the ramp as a model to study speed? | Students will use a model to learn about speed and evaluate a roller coaster system. They take speed measurements using their scale model and use their measurements to determine the necessary height for a real roller coaster. | • Explain why systems are important to scientists.<br>• Recognize scientific models and explain their advantages and limitations.<br>• Use data to determine the relationship between the speed of a car and ramp height. | model<br>system<br>variable |

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| **B2** | **Making Predictions Using a Graph**<br>Pages 59-66<br>50 minutes | Can you predict the speed of the car at any point on the ramp? | Students use a photogate to determine the speed of a car at various points along a ramp. The data is used to make a graph of speed versus position. They then use the graph to predict the speed at a point where they had not placed the photogate. Data is collected to compare the predicted and actual speeds, and they find the percent error and percent correct. | • Determine the speed of the car at various points along the ramp and graph the results.<br>• Use the graph to predict the speed at a chosen point on the ramp.<br>• Measure the actual speed at the chosen point and calculate percent error and percent correct. | dependent variable<br>distance<br>independent variable<br>origin<br>position<br>speed<br>velocity |
| **B3** | **Acceleration**<br>Pages 67-72<br>50 minutes | How is the velocity of the car changing? | Students measure the time it takes for the car to pass through two photogates spaced 30 cm apart on the ramp. The photogate times are used to calculate the two velocities of the car, which are then used to find the acceleration. Comparisons are made among cars on ramps with different slopes. | • Calculate acceleration of a car as it moves down a ramp.<br>• Analyze data to determine the relationship between rate of acceleration and slope of a ramp.<br>• Explain how acceleration is measured. | acceleration<br>velocity |
| **B4** | **Newton's First Law**<br>Pages 73-78<br>50 minutes | What is inertia? | Students will examine the meaning of inertia and analyze collisions between two cars of differing masses to learn about Newton's first law. | • Apply Newton's first law to describe the motion of objects.<br>• Explain the relationship between mass, force, and inertia. | equilibrium<br>inertia<br>net force<br>Newton's first law |
| **B5** | **Newton's Second Law**<br>Pages 79-84<br>50 minutes | How does acceleration depend on force and mass? | Students study the two relationships described by Newton's second law. They first observe the effect of changing an object's mass while the force acting on it remains constant. Force is then changed while mass is kept the same, and the accelerations are compared. | • Identify the relationship between acceleration and mass.<br>• Identify the relationship between acceleration and force.<br>• Explain why Newton's second law is the equation $a = F/m$. | acceleration<br>directly proportional<br>inversely proportional<br>mass<br>newton<br>Newton's second law |
| **B6** | **Newton's Third Law**<br>Pages 85-90<br>50 minutes | What happens when equal and opposite forces are exerted on a pair of cars? | Students will explain the meaning of action–reaction forces and apply knowledge of Newton's laws to explain the resulting motion when objects experience equal and opposite forces. | • Recognize that forces come in pairs with equal strength and opposite direction.<br>• Use Newton's second and third laws to explain the motion that results when objects interact. | collision<br>explosion<br>Newton's third law |
| **B7** | **Collisions and Momentum**<br>Pages 91-98<br>50 minutes | How is momentum exchanged in collisions? | Students collide cars of equal masses and of differing masses. They make qualitative observations about the motion of the cars after each collision. They use Newton's third law and the law of conservation of momentum to explain their observations. | • Make observations about collisions between cars of equal masses and cars of differing masses.<br>• Use Newton's third law to describe the forces on the cars during the collisions.<br>• Recognize that momentum is conserved in all of the collisions. | law of conservation of momentum<br>momentum<br>Newton's third law |

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| B8 | **Collisions and Restraints**<br>Pages 99-104<br>50 minutes or more, depending on selected project constraints | What is the best way to minimize forces during a collision? | Students explore the ways forces interact with objects during a collision. Students use the engineering cycle to design, build, and test a prototype to keep an egg safe in a collision. | • Identify criteria and constraints for an engineering problem.<br>• Use the engineering cycle to design, build, and test a prototype of the solution.<br>• Collect data and use it to make refinements in the solution. | constraints<br>criteria<br>engineering cycle<br>Newton's second law<br>trade-off |
| B9 | **Kinetic and Potential Energy**<br>Pages 105-110<br>50 minutes | What happens to kinetic and potential energy as a car moves down a ramp? | Students determine the kinetic and potential energy of a car at various points as it rolls down a ramp. The total energy at each point is also calculated. Students then construct and analyze a graph showing the kinetic, potential, and total energy at each point. | • Calculate the kinetic, potential, and total energy of a car at various points on a ramp.<br>• Construct a graph of each of the three energy values as a function of position.<br>• Use the law of conservation of energy to explain the changes in the kinetic and potential energy as an object's height decreases. | kinetic energy<br>law of conservation of energy<br>potential energy |
| C1 | **Acceleration and Friction**<br>Pages 111-116<br>50 minutes | How can Newton's second law be used to calculate friction? | Students create a system in which a car is pulled by a string passing over a pulley and holding a mass. The acceleration is experimentally determined and is compared with the theoretical acceleration to determine the friction force. | • Calculate experimental acceleration.<br>• Calculate theoretical acceleration.<br>• Compare the two accelerations and use the result to determine the friction force acting on the system. | acceleration<br>friction<br>net force<br>Newton's second law<br>normal force<br>tension |
| C2 | **Motion on an Inclined Plane**<br>Pages 117-122<br>50 minutes | What determines the acceleration of an object on an inclined plane? | Students measure the acceleration of a car on an inclined plane. They compare the measured acceleration with the theoretical acceleration predicted by Newton's second law. The data is then used to calculate the friction force acting on the car. | • Measure the acceleration of a car on a ramp.<br>• Calculate the car's theoretical acceleration using Newton's second law.<br>• Calculate the friction force acting on the car. | Newton's second law<br>free body diagram |
| C3 | **Acceleration Due to Gravity**<br>Pages 123-128<br>50 minutes | How can a ramp be used to determine the acceleration due to gravity? | Students use a car and ramp to find an experimental value of g. They find the car's acceleration when the ramp is at a range of angles and make a graph of the acceleration versus the sine of the angle of incline. They extrapolate the line of best fit to figure out what the acceleration would be if the ramp were angled at 90 degrees. | • Identify the forces acting on an object on an inclined plane.<br>• Determine the acceleration of a car rolling down a ramp at various angles of incline.<br>• Construct a graph of acceleration versus the sine of the angle of incline and use extrapolation to determine the acceleration due to gravity. | acceleration due to gravity<br>free fall<br>normal force<br>weight |

# Next Generation Science Standards Correlation

CPO Science *Link* investigations are designed for successful implementation of the Next Generation Science Standards. The following chart shows the NGSS Performance Expectations and dimensions that align to the investigations in this title.

| NGSS Performance Expectations | Car and Ramp Investigations |
|---|---|
| MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects. | B6, B8 |
| MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. | A1, A2, A3, A4, A5, A6, A8 |
| MS-PS2-4. Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects. | A7 |
| 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. | B1, B2, B3, B4, B5, C1, C2 |
| 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. | B7 |
| 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. | C3 |
| HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects). | B9 |

# Next Generation Science Standards Correlation (cont'd)

| NGSS Science and Engineering Practices | Car and Ramp Investigations |
|---|---|
| Analyzing and Interpreting Data | B1, B2, B3, B4, B5, C1, C2 |
| Apply scientific ideas or principles to design an object, tool, process, or system | B6, B8 |
| Developing and Using Models | B9 |
| Engaging in Argument from Evidence | A7 |
| Planning and Carrying Out Investigations | A1, A2, A3, A4, A5, A6, A8 |
| Using Mathematics and Computational Thinking | B7, C3 |

| NGSS Disciplinary Core Ideas | Car and Ramp Investigations |
|---|---|
| PS2.A: Forces and Motion | A1, A2, A3, A4, A5, A6, A8, B1, B2, B3, B4, B5, B6, B7, B8, C1, C2 |
| PS2.B: Types of Interactions | A7, B1, B2, B3, B4, B5, C3 |
| PS3.A: Definitions of Energy | B9 |

| NGSS Crosscutting Concepts | Car and Ramp Investigations |
|---|---|
| Cause and Effect | B1, B2, B3, B4, B5, C1, C2 |
| Energy and Matter | B9 |
| Patterns | C3 |
| Stability and Change | A1, A2, A3, A4, A5, A6, A8 |
| Systems and System Models | A7, B6, B7, B8 |

# Common Core State Standards Correlation

| CCSS-Mathematics | | Car and Ramp Investigations |
|---|---|---|
| MP.2 | Reason abstractly and quantitatively. | A1, A2, A3, A4, A5, A6, A8, B1, B2, B3, B4, B5, B6, B7, B8, B9, C1, C2, C3 |
| MP.4 | Model with mathematics. | B1, B2, B3, B4, B5, B7, B9, C1, C2, C3 |
| 6.NS.C.5 | Understand that positive and negative numbers are used together to describe quantities having opposite directions or values; use positive and negative numbers to represent quantities in real-world contexts, explaining the meaning of 0 in each situation. | B6, B8 |
| 6.EE.A.2 | Write, read, and evaluate expressions in which letters stand for numbers. | A1, A2, A3, A4, A5, A6, A8, B6, B8 |
| 7.EE.B.3 | Solve multi-step real-life and mathematical problems posed with positive and negative rational numbers in any form, using tools strategically. Apply properties of operations to calculate with numbers in any form; convert between forms as appropriate; and assess the reasonableness of answers using mental computation and estimation strategies. | A1, A2, A3, A4, A5, A6, A8, B6, B8 |
| 7.EE.B.4 | Use variables to represent quantities in a real-world or mathematical problem, and construct simple equations and inequalities to solve problems by reasoning about the quantities. | A1, A2, A3, A4, A5, A6, A8, B6, B8 |
| 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. | B1, B2, B3, B4, B5, B7, C1, C2, C3 |
| HSN-Q.A.2 | Define appropriate quantities for the purpose of descriptive modeling. | B1, B2, B3, B4, B5, B7, C1, C2, C3 |
| HSN-Q.A.3 | Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. | B1, B2, B3, B4, B5, B7, C1, C2, C3 |
| HSA-SSE.A.1 | Interpret expressions that represent a quantity in terms of its context. | B1, B2, B3, B4, B5, C1, C2, C3 |
| 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. | B1, B2, B3, B4, B5, C1, C2, C3 |
| HSA-CED.A.1 | Create equations and inequalities in one variable and use them to solve problems. | B1, B2, B3, B4, B5, B7, C1, C2 |
| 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. | B1, B2, B3, B4, B5, B7, C1, C2 |
| HSA-CED.A.4 | Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. | B1, B2, B3, B4, B5, B7, C1, C2 |
| 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. | B1, B2, B3, B4, B5, C1, C2 |
| HSS-ID.A.1 | Represent data with plots on the real number line (dot plots, histograms, and box plots). | B1, B2, B3, B4, B5, C1, C2 |

# Common Core State Standards Correlation (cont'd)

| CCSS-English Language Arts & Literacy | | Car and Ramp Investigations |
|---|---|---|
| SL.11-12.5 | Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. | B8 |
| RST.6-8.1 | Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions. | B6, B8 |
| RST.6-8.3 | RST.6-8.3 Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks. | A1, A2, A3, A4, A5, A6, A8, B6, B8 |
| 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. | B1, B2, B3, B4, B5, C1, C2 |
| 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. | B1, B2, B3, B4, B5, C1, C2 |
| WHST.6-8.1 | Write arguments focused on discipline-specific content. | A7 |
| WHST.6-8.7 | Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration. | A1, A2, A3, A4, A5, A6, A8, B6, B8 |
| WHST.9-12.9 | Draw evidence from informational texts to support analysis, reflection, and research. | B1, B2, B3, B4, B5, C1, C2 |