Project-Based Inquiry Science: Vehicles in Motion
Storyline

Targeted Performance Expectations:
· MS-PS2-1 · MS-PS2-2 · MS-PS3-2 · MS-ETS1-1 · MS-ETS1-2 · MS-ETS1-3 · MS-ETS1-4

Unit Goals:
Plan and carry out investigations to explore, define, and explain that when forces act on objects, motion can be changed.
Graphically represent forces in pairs and explain how the force exerted by the first object on the second is equal but in the opposite direction.
Evaluate the number of forces on an object and the strength of the forces and how changes in the forces affect the motion of the object.
Create and evaluate graphical/symbolic representations of motion in systems to understand how changes in motion occur.

Vehicles in Motion: What's the Big Challenge?
Design and Build a Vehicle That Will Go Straight, Far, and Fast, and Carry a Load

Storyline (with Disciplinary Core Ideas and Science Content)	Science and Engineering Practices	Crosscutting Concepts
In the *Introduction* to *Vehicles in Motion*, students are introduced to the *Big Challenge: Design and build a vehicle that will go straight, far, and fast, and carry a load.* To address this real-world challenge students begin by learning about being a design engineer. They are told that they will be working as engineers when they design, systematically test and evaluate, and then redesign their vehicle to meet the expected criteria. They also begin to consider what constitutes a fair test and how a fair test might be used in designing and testing their vehicles. They will use these ideas throughout the unit to design, test, and evaluate the performance of their vehicles. To get started, students explore motion and think about what causes "vehicles," including cars and skateboards, to change motion. They then participate in an exploratory activity ("mess about") with a variety of toy cars that have been selected to introduce students to a variety of ways motion can occur. Using a scaffolded process, students examine the cars for structure, performance, mechanisms, and design and then compare motion-causing mechanisms among the cars. As a whole class, students identify the criteria and constraints for the challenge. They also begin to develop the *Project Board* for the unit, focused on the first two columns (*What do we think we know?* and *what do we need to investigate?*) These will be updated throughout the unit. **Disciplinary Core Ideas:** **ETS1.A: Defining and Delimiting Engineering Problems** · The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (MS-ETS1-1)	**Asking Questions and Defining Problems** (Introduction to the *Big* (design) *Challenge*; identifying the criteria and constraints of the problem; *Create a Project Board*)	Unit Level: **Structure and Function** (causes of motion in a vehicle) Section Level: **Cause and Effect** (how changes in motion are caused)

Vehicles in Motion: Learning Set 1 ***Design and Build a Coaster Car That Goes Straight and Far***		
Storyline (with Disciplinary Core Ideas and Science Content)	**Science and Engineering Practices**	**Crosscutting Concepts**
Introduction to *Learning Set 1*: In *Vehicles in Motion*, students will identify how the changes to variables that cause or impede motion affect the motion of the vehicle they are designing. The iterative design cycle begins in *Learning Set 1*, when they focus their design efforts on designing and building a coaster car that goes straight and far.	**Developing and Using Models** (physical model of a vehicle is used to describe motion) **Engaging in Argument from Evidence** (sharing data and focusing on the criteria of developing a car that will go straight and far) **Analyzing and Interpreting Data** (groups collect vehicle motion data, analyze it and interpret for the goal of creating a vehicle that best meets the challenge criteria)	Unit Level: **Systems and System Models** (representation of inputs and outputs and how energy changes in the system) Section Level: **Stability and Change** (cause of change in motion from different forces) **Cause and Effect** (how changes in motion are caused based on design changes)
Section 1.1: Students begin with a simple coaster car. They build the car within the identified constraints. The groups "mess about" with their coaster car, observing, describing, and recording its motion, making adjustments as necessary. A brief science text introduces students to terms they will use throughout the unit, such as motion, speed, force, propulsion, and gravity. Student groups then demonstrate the performance of their car to the class, sharing their observations, while the teacher pushes them to begin to use the science terms to describe the motion of their car. After their initial work with the vehicle, students engage in a teacher-guided discussion to develop a working definition of motion and the measurement of motion, to compare the motion of different cars in the class, and what constitutes reliable evidence to support claims about motion. The class discusses criteria that can be used to compare the motion of different cars, and students discuss in their small groups what needs to be changed to improve their car's performance. The class updates the *Project Board* with new science knowledge, focusing on what they think they know and what they need to investigate. **Disciplinary Core Ideas:** **ETS1.A: Defining and Delimiting Engineering Problems** · The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (MS-ETS1-1)	**Obtaining, Evaluating, and Communicating Information** (collecting observational data and communicating it to the class for the purposes of evaluating the motion of their cars) **Asking Questions and Defining Problems** (in the context of the vehicle, students ask questions about the motion of the car and define problems that are solvable to meet the challenge)	Unit Level: **Systems and System Models** (representation of inputs and outputs and how energy changes in the system) Section Level: **Stability and Change** (cause of change in motion from different forces) **Cause and Effect** (how changes in motion are caused based on design changes)

Section 1.2: In the previous section, students collected initial qualitative data to describe the motion of their car. In this section, students assume the role of design engineers as they begin to collect quantitative data and try to improve their car's performance. Readings about relative motion and frames of reference, and measuring direction and distance, and the concept of veer provide students with a common language and way to describe and measure the motion of their car. Student groups design and run a procedure to measure the baseline performance of their car. After sharing their observations, and evaluating each group's procedure, the class develops a general procedure they will use throughout the unit to test the performance of their coaster car as it undergoes several design iterations. This process supports student understanding that testing the performance of the original design provides a basis of comparison for judging the effects of changes to that design on the performance of the car. Using the class procedure, each group collects baseline data for their coaster cars. They communicate their baseline results, and develop an explanation about their car's initial performance, which they share with the class. **Disciplinary Core Ideas:** **ETS1.B: Developing Possible Solutions** · A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4) · There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3) · Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3) · Models of all kinds are important for testing solutions. (MS-ETS1-4)	**Developing and Using Models** (physical model of a vehicle is used to describe, predict, and explain motion) **Planning and Carrying Out Investigations** (using vehicle to investigate motion, working in small groups to develop and then carry out class procedures of a "fair test") **Engaging in Argument from Evidence** (sharing data and focusing on the criteria of developing a car that will go straight and far, creating claims about the group's vehicle and its motion and sharing these ideas with others) **Analyzing and Interpreting Data** (groups collect vehicle motion baseline data, for later comparison) **Obtaining, Evaluating, and Communicating Information** (reading about relative motion, frame of reference, and veer, for the purposes of collecting and communicating car performance information) **Constructing Explanations and Designing Solutions** (explaining why the car performed the way it did) **Asking Questions and Defining Problems** (in the context of the vehicle, students ask questions about the motion of the car and define problems that are solvable to meet the challenge) **Using Mathematics, Information and Computer Technology, and Computational Thinking** (students measure and compare their measurements to the whole class, they develop mathematical models for measuring veer and distance)	Unit Level: **Systems and System Models** (baseline data about the car system so that it can later be judged based on changes to the system) Section Level: **Cause and Effect** (how changes in motion are caused based on design changes) **Patterns** (data analyzed for trends to determine patterns in car performance) **Stability and Change** (cause of change in motion from different forces)

Section 1.3: In this section, students focus on one criterion of their design challenge for this unit - to make their car go straight - by accounting for and measuring veer in their class procedure. Student groups modify the class procedure from the previous section to collect and analyze data about the amount of veer at varying distances to a finish line. Using their data they make predictions about where their car will cross a finish line without knowing the exact distance to it beforehand. Groups test their predictions by running three trials, and they analyze their data, determining how accurate their predictions were and why. After presenting their results to the class, which allow students to see data sets larger than their own, the class discusses the importance of being able to predict how their car will perform under different circumstances, and the importance of making careful measurements and keeping accurate records. **Disciplinary Core Ideas:** **ETS1.B: Developing Possible Solutions** · A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4) · There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3) · Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3) · Models of all kinds are important for testing solutions. (MS-ETS1-4)	**Developing and Using Models** (physical model of a vehicle is used to describe, predict, and explain motion) **Planning and Carrying Out Investigations** (using vehicle to investigate motion, working in small groups to develop and then carry out class procedures of a "fair test") **Engaging in Argument from Evidence** (sharing data and focusing on the criteria of developing a car that will go straight and far, creating claims about the group's vehicle and its motion and sharing these ideas with others) **Analyzing and Interpreting Data** (groups collect vehicle motion data, analyze it and interpret for the goal of creating a vehicle that best meets the challenge criteria) **Obtaining, Evaluating, and Communicating Information** (collecting and communicating information from the trial runs of their cars) **Constructing Explanations and Designing Solutions** (identifying ways to design the vehicle to move straight and far) **Using Mathematics, Information and Computer Technology, and Computational Thinking** (students measure and compare their measurements to the whole class, they develop mathematical models for measuring veer and distance)	Unit Level: **Systems and System Models** (representation of inputs and outputs and how energy changes in the system) Patterns (data analyzed for trends to determine patterns in car performance) Section Level: **Cause and Effect** (how changes in motion are caused based on design changes) **Stability and Change** (cause of change in motion from different forces)

Section 1.4: Student groups carefully examine their coaster cars and discuss design and construction factors that may be causing cars to slow down and veer (and thus not meet the criteria for the challenge). Thus, they begin to think about the next criterion for the *Big Challenge* – making the car go far. They share their ideas with the class, and discuss car parts and mechanisms which are most likely to account for poor performance. Students read about how forces cause changes in motion (acceleration), and focus on a particular force, friction, which they read is a force that opposes motion between two surfaces that are in contact. Students read, also, about factors that affect the amount of friction acting on an object, and begin to consider the ways they can minimize friction that may be slowing down their car. These readings support students in developing a common scientific language through which they can describe their observations and ideas about the motion of their coaster car. **Disciplinary Core Ideas:** **PS2.A: Forces and Motion** · The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. (MS-PS2-2)	**Developing and Using Models** (physical model of a vehicle is used to describe, predict, and explain motion and friction) **Engaging in Argument from Evidence** (creating claims about the group's vehicle and factors affecting its motion and sharing these ideas with others) **Obtaining, Evaluating, and Communicating Information** (reading about friction following experiences identifying friction on the vehicle) **Constructing Explanations and Designing Solutions** (identifying ways to minimize friction on the vehicle)	Unit Level: **Structure and Function** (causes of motion in a vehicle) **Systems and System Models** (studying the car as a system of interacting parts) Section Level: **Stability and Change** (cause of change in motion from different forces) **Cause and Effect** (how changes in motion are caused based on design changes)
Section 1.5: Students use and apply their knowledge about friction, what causes it, and how it can be reduced, toward improving their car's performance. They begin this process by carrying out a detailed and systematic examination of their car to identify sources of friction. Viewing their car as a system of interacting parts, they listen for friction, conduct a wheel-spin test, an axle inspection, and compare their car to another group's car. They keep careful records of their inspection, which they share with the class. The class then makes evidence-based claims about the sources and effects of friction on their car. They also discuss ideas about how to reduce each source of friction, and consider how they might modify the construction or design of their car to reduce friction. **Disciplinary Core Ideas:** **ETS1.B: Developing Possible Solutions** · A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4) · There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3) · Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3) · Models of all kinds are important for testing solutions. (MS-ETS1-4)	**Developing and Using Models** (physical model of a vehicle is used to describe, predict, and explain motion and friction) **Engaging in Argument from Evidence** (sharing data and focusing on the criteria of developing a car that will go straight and far, creating claims about the group's vehicle and its motion and sharing these ideas with others) **Analyzing and Interpreting Data** (groups collect observational data about sources of friction in their car, analyze it and interpret for the goal of creating a vehicle that best meets the challenge criteria) **Obtaining, Evaluating, and Communicating Information** (reading about friction following experiences identifying friction on the vehicle) **Constructing Explanations and Designing Solutions** (identifying ways to minimize friction)	Unit Level: **Structure and Function** (causes of friction in a vehicle) **Systems and System Models** (studying the car as a system of interacting parts, and changes to one part affect other parts) Section Level: **Cause and Effect** (how changes in motion are caused based on design changes) **Stability and Change** (cause of change in motion from different forces)

Section 1.6: Now that students have determined sources of friction and possible ways to minimize the friction on their coaster car, they engage in an iterative design process to improve their car's performance. By engaging in an iterative process of design and testing, students are reminded about the importance of collecting baseline data. They also learn about the importance of changing and testing one variable at a time, and keeping careful records of changes made and outcomes on the car's performance. They test the performance of their car using the procedure they developed as a class in *Section 1.2*. Student groups share the results of their redesign process with the class. As individuals, students then develop a set of design recommendations, which consist of evidence-based claims, about the challenge. Specifically, students use the results of their redesign to make recommendations for how to make the coaster car travel very far, travel very straight, and very far and very straight. Students share their recommendations with their group, and the group decides on a set of recommendations to present to the class. The class discusses the recommendations, and comes to consensus about which to add to the *Project Board*. These recommendations will be revisited and revised later in the unit as students build upon their knowledge. **Disciplinary Core Ideas:** **ETS1.B: Developing Possible Solutions** · A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4) · There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3) · Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3) · Models of all kinds are important for testing solutions. (MS-ETS1-4)	**Developing and Using Models** (physical model of a vehicle is used to describe, predict, and explain motion and friction) **Planning and Carrying Out Investigations** (using vehicle to investigate motion, working in small groups to carry out class procedures) **Engaging in Argument from Evidence** (sharing data and focusing on the criteria of developing a car that will go straight and far, creating claims about the group's vehicle and its motion and sharing these ideas with others) **Analyzing and Interpreting Data** (groups collect vehicle motion data, analyze it and interpret for the goal of creating a vehicle that best meets the challenge criteria) **Obtaining, Evaluating, and Communicating Information** (collecting data from design iterations, sharing them with the class, and evaluating the information to make recommendations; updating the *Project Board*) **Constructing Explanations and Designing Solutions** (identifying ways to design the vehicle to move straight and far – making design recommendations) **Using Mathematics, Information and Computer Technology, and Computational Thinking** (students measure and compare their measurements to the whole class)	Unit Level: **Structure and Function** (causes of friction in a vehicle) **Systems and System Models** (studying the car as a system of interacting parts, and changes to one part affect other parts) Section Level: **Cause and Effect** (how changes in motion are caused based on design changes) **Patterns** (data analyzed for trends to determine patterns in car performance) **Stability and Change** (cause of change in motion)

Section 1.7: Now that the students have spent several lessons focused on designing a coaster car to go straight and travel far, they begin to learn about the next criterion of the challenge – to make the car travel fast. As they did with making their car meet the criteria of straight and far, students begin this section by considering how the criterion of speed can be measured and described. Students read briefly about speed, and discuss how it is different from velocity. Groups then discuss how speed might be measured, hypothesizing an initial mathematical relationship between the units used to describe speed. As they read more about average speed, they learn the relationship between speed, time, and distance, as well as that speed and motion can be represented in distance-time graphs. After discussing the variables that need to be measured in order to determine the speed at which their car travels, and how those measurements can be made, student groups use what they learned earlier in the unit about the importance of fair tests, to design a procedure for measuring the speed of a car. After an iterative procedure planning cycle, the class collaborates to develop a procedure to measure the speed of their cars. Using this class procedure groups collect speed trial data, which they share with the class. Based on the larger class data set, they discuss the features of the best-performing cars that seemed to enable them to move faster. During this discussion, students are expected to be able to incorporate their knowledge about the relationships between friction and speed, and speed and velocity. **Disciplinary Core Ideas:** **ETS1.B: Developing Possible Solutions** · A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4) · There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3) · Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3) · Models of all kinds are important for testing solutions. (MS-ETS1-4)	**Developing and Using Models** (physical model of a vehicle is used to describe, predict, and explain motion, speed, and friction) **Planning and Carrying Out Investigations** (using vehicle to investigate speed, working in small groups to develop and then carry out class procedures of a "fair test") **Engaging in Argument from Evidence** (sharing data and focusing on the criteria of developing a car that will go fast, creating claims about the group's vehicle and its motion and sharing these ideas with others) **Analyzing and Interpreting Data** (groups collect vehicle speed data, analyze it and interpret for the goal of creating a vehicle that best meets the challenge criteria) **Obtaining, Evaluating, and Communicating Information** (reading about speed and velocity; collecting and evaluating speed data, sharing with the class.) **Constructing Explanations and Designing Solutions** (identifying ways to design the vehicle to move fast) **Using Mathematics, Information and Computer Technology, and Computational Thinking** (students measure and compare their measurements to the whole class, they develop mathematical models for measuring speed, they sketch changes in motion and graph motion data)	Unit Level: **Structure and Function** (what features of the car allow it to go faster) **Systems and System Models** (studying the car as a system of interacting parts, and changes to one part affect other parts) Section Level: **Cause and Effect** (how changes in motion are caused based on design changes) **Stability and Change** (cause of change in motion) **Patterns** (data analyzed for trends to determine patterns in car performance)

Section 1.8: Now that students have had the opportunity to evaluate their car designs in relation to the criterion of speed, they enter their car in a "competition" against other cars to further explore the mathematical relationship described by speed equation. Groups choose one of three competitions in which one variable of the speed equation is unknown. In each competition, groups are making predictions about the performance of their car relative to the time it will take their car to reach a finish line, predict the distance required to reach a finish line in a certain amount of time, or they must arrange for a collision of two cars at a specific point. Groups participating in the same competition work together to discuss and plan a procedure, following some basic guidelines provided in the text, that will allow them to collect the data needed to make the required prediction for their competition. Each group then runs their procedure, collects data, and makes their prediction. After sharing their prediction with the class, each group's prediction is tested with the whole class, and the class discusses the characteristics of procedures that resulted in the most accurate predictions. This section concludes with a class discussion of the relationship between speed, distance, and time, and the *Project Board* is updated. **Disciplinary Core Ideas:** **ETS1.B: Developing Possible Solutions** · A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4) · There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3) · Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3) · Models of all kinds are important for testing solutions. (MS-ETS1-4)	**Planning and Carrying Out Investigations** (using vehicle to investigate motion, working in small groups to develop and then carry out class procedures of a "fair test") **Engaging in Argument from Evidence** (sharing data and focusing on the relationship between speed, distance, and time; making predictions about the group's vehicle performance, and sharing these ideas with others) **Analyzing and Interpreting Data** (groups collect vehicle motion data, analyze it and interpret for the goal of making predictions) **Constructing Explanations and Designing Solutions** (making predictions based on evidence) **Using Mathematics, Information and Computer Technology, and Computational Thinking** (students examine the mathematical relationship between speed, time, and distance)	Section Level: **Stability and Change** (cause of change in motion)

Section 1.9: Students have spent the *Learning Set* engaged with learning about motion and forces that affect motion. In one of the competitions in the last section they observed collisions between cars. In this section they read about the effects of multiple forces acting upon an object at the same time. They see in the text how the magnitude and direction of forces acting on an object can be represented with arrows in a force diagram. They then have the opportunity to practice drawing force diagrams to represent the forces acting on objects in everyday experiences. They read about how the forces acting on an object combine to act as a single net force, and how balanced and unbalanced forces affect motion. Students extend their understanding of the concepts by working with their group to draw a motion storyboard for their original coaster car (baseline) and their current coaster car, given the changes they have made. The motion storyboard shows, through symbolic representations (force diagrams), the forces acting on the coaster car and how these forces change as the car travels from its starting position at the top of the ramp, to its ending position where it rolls to a stop. Using these motion storyboards, and previously collected data, students create an explanation of why their current coaster car travels straighter, and farther than their original car did. After sharing their explanations with the class, students discuss what they have learned about motion and forces, and they update the *Project Board.* The storyboards created here will be used later in the unit, in addition to the quantitative data they collect; to help students make visual comparisons and descriptions of design changes to their cars and the impacts those changes have on the car's performance. **Disciplinary Core Ideas:** **PS2.A: Forces and Motion** · The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. (MS-PS2-2) · 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. (MS-PS2-2)	**Developing and Using Models** (force diagram is used to describe, predict, and explain motion) **Engaging in Argument from Evidence** (sharing their explanations with the class) **Obtaining, Evaluating, and Communicating Information** (reading about forces acting on a single object and the impact on the motion of that object; updating *Project Board*) **Constructing Explanations and Designing Solutions** (creating explanations) **Asking Questions and Defining Problems** (updating *Project Board*)	Section Level: **Stability and Change** (cause of change in motion)

Back to the Big Challenge: Students are developing a recommendation, consistent with the criteria and constraints of the challenge, for designing a coaster car that will go straight and far. They now revise their recommendation based on the results of iterative rounds of investigation from *Learning Set 1*. After they complete the first recommendation they share it and then revise it based on what they learn from others. **Disciplinary Core Ideas:** **ETS1.C: Optimizing the Design Solution** · Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (MS-ETS1-3) · The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (MS-ETS1-4)	**Asking Questions and Defining Problems** (the process of developing recommendations helps refine the unit problem and develop additional science questions that can be investigated) **Obtaining, Evaluating and Communicating Information** (creating and evaluating presentations about recommendations requires synthesizing information about factors that change motion and provide all students with information critical to addressing the challenge) **Constructing Explanations and Designing Solutions** (students create recommendations using gathered evidence for how to design, build, and test a vehicle that meets the design challenges, they revise their recommendations based on the data of others) **Engaging in Argument from Evidence** (recommendations are shared with others, students begin to use evidence from their investigations to create an explanation/ recommendation that is supported by evidence)	Unit Level: **Systems and System Models** (representation of inputs and outputs and how energy changes in the system) Section Level: **Stability and Change** (cause of change in motion from different forces) **Cause and Effect** (how changes in motion are caused based on design changes)

Vehicles in Motion: Learning Set 2 Propeller-Car Challenge		
Storyline (with Disciplinary Core Ideas and Science Content)	**Science and Engineering Practices**	**Crosscutting Concepts**
Introduction to *Learning Set 2*: Students are introduced to the idea of using a propulsion system (propeller) rather than the ramp (used in *Learning Set 1*) to get the coaster car moving.	**Engaging in Argument from Evidence** (sharing & discussing categorizations for different vehicle motion) **Obtaining, Evaluating, and Communicating Information** (reading focused on forces, energy, and work, and providing language to be used in subsequent discussions) **Asking Questions and Defining Problems** (in the context of the vehicle's motion and variables that affect motion, students ask questions about the motion of the vehicle, forces acting on the vehicle, and how they can change motion, and define problems that are solvable to meet the challenge; update the *Project Board*)	Unit Level: **Structure and Function** (what features of a car get it moving and keep it moving) **Systems and System Models** (studying the car as a system of interacting parts, and changes to one part affect other parts; addition of propulsion subsystem) Section Level: **Cause and Effect** (how changes in motion are caused based on design changes) **Stability and Change** (cause of change in motion of a vehicle)
Section 2.1: To immerse them in the idea of propulsion to power their cars, student groups consider different types of vehicles, and think about why a propulsion system is needed to get a vehicle to move and keep it moving. They brainstorm a class list of propulsion systems, classifying them by the factors they all have in common (e.g., energy sources, mechanisms that convert energy, and functions). Students read about forces, energy, and work. In particular, the reading helps support student understanding of how energy, forces, and work are related to the design of a propulsion system, and that when energy acts on matter it does so in the form of a force. Students review the list of criteria and constraints they developed in *Learning Set 1*. Because adding the propulsion system changes the design of the car, they apply their developing understanding of the relationship between forces, energy, and work, and their initial ideas about propulsion, to identify new criteria and constraints that will impact their propulsion system design. They then update the *Project Board.* **Disciplinary Core Ideas:** **ETS1.A: Defining and Delimiting Engineering Problems** · The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (MS-ETS1-1)		

Section 2.2: Students add the propulsion system (propeller) to their car from *Learning Set 1.* After messing about with the propulsion system to see how it affects the car's motion students consider what changes could be made to the propeller car that would make it travel farther. Through a reading, students revisit the concept of combining forces to examine how the sum of a propulsion force and friction will produce a net force, which will affect the motion of their car. Given the qualitative data collected from their mess about, students identify variables that seem to affect the motion of the car. Each variable (factor) becomes a question to be investigated in the next section. They update the criteria and constraints and update the *Project Board* for the new challenge. **Disciplinary Core Ideas:** **ETS1.A: Defining and Delimiting Engineering Problems** · The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (MS-ETS1-1)	**Developing and Using Models** (physical model of a vehicle is used to describe, predict, and explain motion and forces that change motion) **Engaging in Argument from Evidence** (sharing data and focusing on the criteria of developing a propeller car that will go straight and far and fast) **Analyzing and Interpreting Data** (groups collect vehicle motion mess about data, and interpret it for the goal of creating a vehicle that best meets the challenge criteria) **Obtaining, Evaluating, and Communicating Information** (reading focused on forces, creating symbolic representations of forces, demonstrating frame of reference, and providing language to be used in subsequent discussions) **Asking Questions and Defining Problems** (in the context of the vehicle's motion and variables that affect motion, students identify new criteria and constraints, identify variables to be tested)	Unit Level: **Structure and Function** (what features of a car get it moving and keep it moving) **Systems and System Models** (studying the car as a system of interacting parts, and changes to one part affect other parts; addition of propulsion subsystem) Section Level: **Cause and Effect** (how changes in motion are caused based on design changes) **Stability and Change** (cause of change in motion of a vehicle)

Section 2.3: Using the results of the *Mess About* data from the previous section (which was also placed on the *Project Board*), each group chooses one variable they think will affect the performance of the propeller car, and plans and conducts an investigation to examine the effects of that variable. In this section, the students engage in a scientific experimental process (they previously have participated in engineering iterative design processes). As part of this process, they first develop a plan to conduct their experiment. They determine the variables (independent, dependent, and controlled) in their experiment. They formulate a hypothesis, and design a procedure to test their chosen variable. Students have the opportunity to share their plan with, and receive feedback from the class to improve their design. They revise their plan as necessary, then conduct their experiment. They analyze their results, looking for trends in their data. Each group uses the results of their investigation to develop a recommendation to address the design challenge and shares their investigation, results, and recommendation with the class, in particular focusing on how the variable they investigated did or did not affect the performance of the propeller car. **Disciplinary Core Ideas:** **ETS1.B: Developing Possible Solutions** · A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4) · There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3) · Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3) · Models of all kinds are important for testing solutions. (MS-ETS1-4)	**Planning and Carrying Out Investigations** (using vehicle to investigate motion, working in small groups to develop and then carry out class procedures to test variables' effect on car motion) **Engaging in Argument from Evidence** (sharing data and focusing on the criteria of developing a propeller car that will go straight and far and fast, creating claims/ recommendations about the group's vehicle and its motion and sharing these ideas with others) **Analyzing and Interpreting Data** (groups collect vehicle motion data, analyze it, and interpret it for the goal of creating a vehicle that best meets the challenge criteria; looking for trends in data) **Obtaining, Evaluating, and Communicating Information** (students communicate their plans, and their recommendations to the class) **Constructing Explanations and Designing Solutions** (students create recommendations using gathered evidence for how to design, build, and test a vehicle that meets the design challenges, they revise their recommendations based on the data of others) **Using Mathematics, Information and Computer Technology, and Computational Thinking** (students measure and compare their measurements to those of other groups, they develop mathematical models for measuring, they sketch changes in motion and graph motion data, they create symbolic representations of forces and how changes in force affect the motion of the vehicle)	Unit Level: **Structure and Function** (what features of a car get it moving and keep it moving) **Systems and System Models** (studying the car as a system of interacting parts, and changes to one part affect other parts; addition of propulsion subsystem) Section Level: **Cause and Effect** (how changes in motion are caused based on design changes) **Patterns** (data analyzed for trends to determine relationship between changing a variable and car performance) **Stability and Change** (cause of change in motion of a vehicle)

Section 2.4: In this section, students consider the ways in which their propeller motor generates a propulsion force. Students begin this section by working with their groups to think about and describe the forces acting on the propeller car, and how these forces cause it to move. The groups share these ideas and the class develops a list. Students are introduced to the concept of forces in pairs (action-reaction forces) in a reading. This concept is reinforced and clarified for students as they engage in a series of quick investigations of pairs of forces. Students analyze their data from these investigations in light of the paired forces that are at work in each investigation. Students then read about examples of action-reaction forces acting on a variety of objects to cause motion. They are then supported, through a reading, in understanding how action-reaction forces can be related to the concepts of mass, weight, and gravity. Students apply this concept of action-reaction to understanding the force pairs at work when their propeller motor generates a force of propulsion. Students investigate the effects of the force of propulsion on the performance of their propeller car by repeating the same experiment from the previous section, this time measuring the net force on their car. They analyze their data, and by comparing their force data in this section to their distance data in the previous section, they determine the relationship between the size of the net force and car performance. Similar to the motion storyboards they created in *Learning Set 1*, students create motion storyboards showing how the propulsion force, friction, and net force changed with each change in their independent variable. Using the data collected from their experiments, and their storyboards (force diagrams at different "stages"), they revise their previous recommendation for the challenge. **Disciplinary Core Ideas:** **PS2.A: Forces and Motion** · The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. (MS-PS2-2) · 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. (MS-PS2-2)	**Developing and Using Models** (physical model of a vehicle is used to describe, predict, and explain motion and forces that change motion, graphical representations of motion and forces serve to help students generate predictions and explanations of forces) **Planning and Carrying Out Investigations** (using vehicle to investigate motion, working in small groups to develop and then carry out class procedures to test variables' effect on motion) **Engaging in Argument from Evidence** (sharing data and focusing on the criteria of developing a propeller car that will go straight and far and fast, creating claims about the group's vehicle and its motion and sharing these ideas with others) **Analyzing and Interpreting Data** (groups collect vehicle motion data, analyze it, and interpret it for the goal of creating a vehicle that best meets the challenge criteria) **Obtaining, Evaluating, and Communicating Information** (reading focused on action-reaction forces, mass, weight, and gravity; providing language to be used in subsequent discussions) **Constructing Explanations and Designing Solutions** (students create recommendations using gathered evidence for how to design, build, and test a vehicle that meets the design challenges, they revise their recommendations based on the data of others) **Using Mathematics, Information and Computer Technology, and Computational Thinking** (students measure and compare their measurements to those of other groups, they develop mathematical models for measuring, they sketch changes in motion and graph motion data, they create symbolic representations of forces and how changes in force affect the motion of the vehicle)	Unit Level: **Structure and Function** (what features of a car get it moving and keep it moving) **Systems and System Models** (studying the car as a system of interacting parts, and changes to one part affect other parts; addition of propulsion subsystem) Section Level: **Cause and Effect** (how changes in motion are caused based on design changes) **Patterns** (data analyzed for trends to determine relationship between force and car performance) **Stability and Change** (cause of change in motion of a vehicle)

Section 2.5: Students continue working as design engineers and engage in an iterative design process to design and build their best propeller car. After having the opportunity to work individually to design a propeller motor that will generate the greatest force of propulsion, thereby causing the car to travel the farthest, students meet with their groups to discuss their design plans and come to consensus on a best propeller design. Groups share their best design plan, and rationale, with the class, and revise their design based on feedback and others' ideas. After building and testing their best design, students engage in an iterative design process (changing one variable at a time, recording data on the outcome, making revisions to the design). With their best design after the iterative process, students evaluate the performance of the car using a new performance test. They measure changes in speed that occur during different intervals along the car's path. Using their data from this performance test, they create another motion storyboard to show the forces acting on their car during each of the intervals in their test. Examining their storyboard, students determine the relationship between net force and average speed. The class compares the performance of each group's best designs and reflects on reasons for variations in performance, and how the car designs may be further improved. **Disciplinary Core Ideas:** **ETS1.B: Developing Possible Solutions** · A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4) · There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3) · Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3) · Models of all kinds are important for testing solutions. (MS-ETS1-4)	**Developing and Using Models** (physical model of a vehicle is used to describe, predict, and explain motion and forces that change motion, graphical representations of motion and forces serve to help students generate predictions and explanations of forces) **Planning and Carrying Out Investigations** (using vehicle to investigate motion, working in small groups to develop and then carry out class procedures to test variables' effect on motion) **Engaging in Argument from Evidence** (sharing data and focusing on the criteria of developing a propeller car that will go straight and far and fast, creating claims about the group's vehicle and its motion and sharing these ideas with others) **Analyzing and Interpreting Data** (groups collect vehicle motion data, analyze it, and interpret it for the goal of creating a vehicle that best meets the challenge criteria) **Obtaining, Evaluating, and Communicating Information** (communicating information about car performance) **Constructing Explanations and Designing Solutions** (students create recommendations using gathered evidence for how to design, build, and test a vehicle that meets the design challenges, they revise their recommendations based on the data of others) **Using Mathematics, Information and Computer Technology, and Computational Thinking** (students measure and compare their measurements to those of other groups, they develop mathematical models for measuring, they sketch changes in motion and graph motion data, they create symbolic representations of forces and how changes in force affect the motion of the vehicle)	Unit Level: **Structure and Function** (what features of a car get it moving and keep it moving) **Systems and System Models** (studying the car as a system of interacting parts, and changes to one part affect other parts; addition of propulsion subsystem) Section Level: **Cause and Effect** (how changes in motion are caused based on design changes) **Patterns** (data analyzed for trends to patterns in car performance) **Stability and Change** (cause of change in motion of a vehicle)

Section 2.6: Students begin this section by comparing their coaster car storyboard from *Learning Set 1* to their propeller car storyboard, noting similarities and differences, and considering why the average speed changes from interval to interval. Using the guidance of a reading, students relate what is happening at different stages in their storyboards to the concept, introduced briefly in *Learning Set 1*, of acceleration. Specifically, students recognize that changes in motion, or accelerations, are the result of net forces acting on the car. Further, they begin to apply these concepts toward thinking about how they can achieve the best performance of their car. In light of these new connections students make between the design changes to their propeller cars and the net force (and thus acceleration and motion) of their car, students are encouraged to revise their previous propeller car recommendations, adding more of this science knowledge to support the claims and evidence. They share their revised recommendations with the class. A *More to Learn* reading introduces students more formally to Sir Isaac Newton, and his laws of motion, which will be reinforced later in the unit. **Disciplinary Core Ideas:** **PS2.A: Forces and Motion** · For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law). (MS-PS2-1) · 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. (MS-PS2-2) · 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. (MS-PS2-2)	**Constructing Explanations and Designing Solutions** (students update their recommendations adding science knowledge.) **Using Mathematics, Information and Computer Technology, and Computational Thinking** (students sketch changes in motion and graph motion data, they create symbolic representations of forces and how changes in force affect the motion of the vehicle)	Unit Level: **Structure and Function** (what features of a car get it moving and keep it moving) **Systems and System Models** (studying the car as a system of interacting parts, and changes to one part affect other parts; addition of propulsion subsystem) Section Level: **Cause and Effect** (how changes in motion are caused based on design changes) **Patterns** (data analyzed for trends to patterns in car performance) **Stability and Change** (cause of change in motion of a vehicle)
Back to the Big Challenge: Students begin thinking about the *Big Challenge*, based on what they learned in *Learning Set 2*. Using their knowledge and experiences with forces and motion, groups are asked to predict how their propeller car would perform under different conditions, including carrying a load and traveling over rough terrain. These new situations relate to the work students will complete in *Learning Set 3*. Additionally, students also have to predict the changes they would have to make to their car, or its propulsion system, so that it could perform better under each of the conditions. To support all of these claims students are asked to make, they must use symbolic representations (force diagrams), and draw on their science knowledge, and previous recommendations made by the class. This activity leads students to identify more things they will need to investigate to meet the challenge. Student groups share and update the *Project Board* with all of these ideas. **Disciplinary Core Ideas:** **ETS1.C: Optimizing the Design Solution** · Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (MS-ETS1-3) · The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (MS-ETS1-4)	**Developing and Using Models** (physical model of a vehicle is used to describe, predict, and explain motion and forces that change motion, graphical representations of motion and forces serve to help students generate predictions and explanations of forces) **Engaging in Argument from Evidence** (sharing data and focusing on the criteria of developing a propeller car that will meet the described design challenges and sharing these ideas with others) **Constructing Explanations and Designing Solutions** (students create recommendations using gathered evidence for how to design, build, and test a vehicle that meets the design challenges)	Unit Level: **Systems and System Models** (studying the car as a system of interacting parts, and changes to one part affect other parts; addition of propulsion subsystem) Section Level: **Cause and Effect** (how changes in motion are caused based on design changes) **Stability and Change** (cause of change in motion from different forces)

Vehicles in Motion: Learning Set 3
How Will Carrying a Load Affect Your Vehicle's Performance?

<table>
<tr><th>Storyline (with Disciplinary Core Ideas and Science Content)</th><th>Science and Engineering Practices</th><th>Crosscutting Concepts</th></tr>
<tr><td>Introduction to Learning Set 3:
Using the same propeller car as in Learning Set 2, students investigate how adding weight to the car will affect the car's performance.</td>
<td rowspan="2">Developing and Using Models (physical model of a vehicle is used to describe, predict, and explain motion and forces that change motion, graphical representations of motion and forces serve to help students generate predictions and explanations of forces)

Planning and Carrying Out Investigations (using vehicle to investigate motion, working in small groups to develop and then carry out class procedures to test the effect of variables on motion)

Engaging in Argument from Evidence (sharing data and focusing on the criteria of developing a car that will go straight and far and fast, and carry a load, creating claims about the group's vehicle and its motion and sharing these ideas with others)

Analyzing and Interpreting Data (groups collect vehicle motion data, analyze it, and interpret it for the goal of creating a vehicle that best meets the challenge criteria)

Obtaining, Evaluating, and Communicating Information (update the criteria and constraints, and the Project Board)

Asking Questions and Defining Problems (students ask questions about the motion of the vehicle, and the effect of mass on car performance)

Using Mathematics, Information and Computer Technology, and Computational Thinking (students measure and compare their measurements to the whole class, they develop mathematical models for measuring, they sketch changes in motion and graph motion data, they create symbolic representations of forces and how changes in force affect the motion of the vehicle)</td>
<td rowspan="2">Unit Level:
Systems and System Models (studying the car as a system of interacting parts, and changes to one part affect other parts; addition of propulsion subsystem)

Section Level:
Cause and Effect (how changes in motion are caused based on design changes)
Stability and Change (cause of change in motion from different forces)</td></tr>
<tr><td>Section 3.1:
So far in this unit students have measured their car's performance in several ways: average speed during different intervals, distance the car veers from centerline, and net force on the car. To begin this Learning Set, students use these same procedures to measure their car's performance with and without additional mass to determine the effect of mass on motion, and their car's performance. They use symbolic and mathematical representations (force diagrams) to compare and reflect on why the car performs differently with and without the load.
Because the challenge has changed again, students update the criteria and constraints for the challenge. The class updates the Project Board with their ideas about mass, motion, and car performance.

Disciplinary Core Ideas:
ETS1.B: Developing Possible Solutions
· A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4)
· There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3)
· Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3)
· Models of all kinds are important for testing solutions. (MS-ETS1-4)</td></tr>
</table>

Section 3.2: After reading about direct and inverse mathematical relationships, the students use guidance provided in the text to explore the relationships between force, mass, and acceleration described in Newton's Second Law. Using a series of simple numerical examples, these mathematical relationships are analyzed and students consider how changing any one of the variables will affect the others. They also have the opportunity to apply this concept to explaining qualitative examples. Students then begin to consider how Newton's Second Law applies to the motion and performance of their propeller car. **Disciplinary Core Ideas:** **PS2.A: Forces and Motion** · The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. (MS-PS2-2)	**Obtaining, Evaluating, and Communicating Information** (reading focused on Newton's second law, and providing language to be used in subsequent discussions) **Using Mathematics, Information and Computer Technology, and Computational Thinking** (students develop mathematical models for measuring, they sketch changes in motion and graph motion data, they create symbolic representations of forces and how changes in force affect the motion of the vehicle)	Section Level: **Stability and Change** (cause of change in motion from different forces)

Section 3.3: Now that students have been introduced to the relationship between force, mass, and acceleration, they plan and conduct an experiment to further explore the effect of mass on the acceleration of their propeller car. As they begin to think about how to plan their experiment, students recognize the challenges associated with directly measuring acceleration. A reading on acceleration and speed provides students with more guidance, specifically, that they can use indicators of acceleration to help them determine some measure of acceleration. Another reading supports students in recognizing time as a useful indicator of acceleration, as they examine the equation for acceleration. The knowledge in these readings supports students in their design of an experiment to measure the effect of mass on their car's acceleration. They conduct their experiment, and analyze their results for trends. Using the trends identified in their data, students make claims connecting the variables of mass, acceleration, and force, and explain the relationship between mass and the acceleration of their propeller car. After the class has heard presentations from all groups, students update their explanations of motion based on all data available to them. **Disciplinary Core Ideas:** **ETS1.B: Developing Possible Solutions** · A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4) · There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3) · Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3) · Models of all kinds are important for testing solutions. (MS-ETS1-4)	**Developing and Using Models** (physical model of a vehicle is used to describe, predict, and explain motion and forces that change motion, graphical representations of motion and forces serve to help students generate predictions and explanations of forces) **Planning and Carrying Out Investigations** (using vehicle to investigate motion, working in small groups to develop and then carry out class procedures to test the effect of variables on motion) **Engaging in Argument from Evidence** (sharing data and focusing on the criteria of developing a car that will go straight and far and fast, and carry a load, creating claims about the group's vehicle and its motion and sharing these ideas with others) **Analyzing and Interpreting Data** (groups collect vehicle motion data, analyze it, and interpret it for the goal of creating a vehicle that best meets the challenge criteria) **Obtaining, Evaluating, and Communicating Information** (reading focused on acceleration and speed, and providing language to be used in subsequent discussions) Constructing Explanations and Designing Solutions (students create recommendations using gathered evidence for how to design, build, and test a vehicle that meets the design challenges, they revise their recommendations based on the data of others) **Using Mathematics, Information and Computer Technology, and Computational Thinking** (students measure and compare their measurements to the whole class, they develop mathematical models for measuring, they sketch changes in motion and graph motion data, they create symbolic representations of forces and how changes in force affect the motion of the vehicle)	Unit Level: **Structure and Function** (what features of a car get it moving and keep it moving) **Systems and System Models** (studying the car as a system of interacting parts, and changes to one part affect other parts; addition of propulsion subsystem) Section Level: **Cause and Effect** (how changes in motion are caused based on design changes) **Patterns** (data analyzed for trends to patterns in car performance) **Stability and Change** (cause of change in motion of a vehicle)

Section 3.4: This section presents students with a new challenge in which students must apply what they have learned about force, mass, and acceleration, and their car's propulsion system to determine how to get their car to travel a specific distance and then stop "on a dime." Through sharing of ideas and iterative design cycles, students test their designs and see how closely they can come to meeting the challenge. Students also learn about the concept of tradeoffs in design. **Disciplinary Core Ideas:** **ETS1.B: Developing Possible Solutions** · A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4) · There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3) · Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3) · Models of all kinds are important for testing solutions. (MS-ETS1-4)	**Developing and Using Models** (physical model of a vehicle is used to describe, predict, and explain motion and forces that change motion, graphical representations of motion and forces serve to help students generate predictions and explanations of forces) **Planning and Carrying Out Investigations** (using vehicle to investigate motion, working in small groups to develop and then carry out class procedures to test the effect of variables on motion) **Engaging in Argument from Evidence** (sharing data and focusing on the criteria of developing a car that will go straight and far and fast, and carry a load, creating claims about the group's vehicle and its motion and sharing these ideas with others) **Analyzing and Interpreting Data** (groups collect vehicle motion data, analyze it, and interpret it for the goal of creating a vehicle that best meets the challenge criteria) **Constructing Explanations and Designing Solutions** (students create recommendations using gathered evidence for how to design, build, and test a vehicle that meets the design challenges) **Using Mathematics, Information and Computer Technology, and Computational Thinking** (students measure and compare their measurements to the whole class, they develop mathematical models for measuring, they sketch changes in motion and graph motion data, they create symbolic representations of forces and how changes in force affect the motion of the vehicle)	Unit Level: **Structure and Function** (what features of a car get it moving and keep it moving, and cause it to stop) **Systems and System Models** (studying the car as a system of interacting parts, and changes to one part affect other parts; addition of propulsion subsystem) Section Level: **Cause and Effect** (how changes in motion are caused based on design changes) **Patterns** (data analyzed for trends to patterns in car performance) **Stability and Change** (cause of change in motion of a vehicle)

Section 3.5: Throughout the unit students have been making observations and conducting investigations about objects in the "real world." In this section, students are introduced to the notion of thought experiments, as another way scientists are able to do their work and learn about the world. After reading about each of Newton's Laws of motion, students engage in a series of thought experiments and reflections related to each Law. These experiences support students in extending and applying their knowledge of the concepts they have been exploring throughout the unit with their cars. This science knowledge will be used by students to help them make good design decisions and achieve the *Big Challenge*. **Disciplinary Core Ideas:** **PS2.A: Forces and Motion** · For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law). (MS-PS2-1) · 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. (MS-PS2-2) · 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. (MS-PS2-2) **ETS1.B: Developing Possible Solutions** · A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4) · There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3) · Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3) · Models of all kinds are important for testing solutions. (MS-ETS1-4)	**Developing and Using Models** (graphical representations of motion and forces serve to help students generate predictions and explanations of forces) **Planning and Carrying Out Investigations** (students carry out thought experiments) **Obtaining, Evaluating, and Communicating Information** (reading focused Newton's Laws, and providing language to be used in subsequent discussions) **Using Mathematics, Information, and Computer Technology and Computational Thinking** (students develop create symbolic representations of forces and how changes in force affect the motion of the vehicle)	Unit Level: **Systems and System Models** (studying the car as a system of interacting parts, and changes to one part affect other parts; addition of propulsion subsystem) Section Level: **Stability and Change** (cause of change in motion of a vehicle)

Section 3.6: Similar to *Section 3.4*, this section presents students with two new challenges in which students must apply what they have learned about the Laws of Motion, and their car's propulsion system to determine how to get their car to carry the heaviest load possible either over a hill or across rough terrain in the shortest time possible. After considering the criteria and constraints for these new challenges, students plan, share ideas and engage in iterative design cycles, to test their designs and see how closely they can come to meeting the challenge. As the final design challenge before addressing the *Big Challenge*, students employ the experimental and design skills, and knowledge they have learned throughout the unit to collect more data that can be used to help them address the *Big Challenge*. **ETS1.B: Developing Possible Solutions** · A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4) · There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3) · Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3) · Models of all kinds are important for testing solutions. (MS-ETS1-4)	**Developing and Using Models** (physical model of a vehicle is used to describe, predict, and explain motion and forces that change motion, graphical representations of motion and forces serve to help students generate predictions and explanations of forces) **Planning and Carrying Out Investigations** (using vehicle to investigate motion, working in small groups to develop and then carry out class procedures to test the effect of variables on motion) **Engaging in Argument from Evidence** (sharing data and focusing on the criteria of developing a car that will go straight and far and fast, and carry a load, creating claims about the group's vehicle and its motion and sharing these ideas with others) **Analyzing and Interpreting Data** (groups collect vehicle motion data, analyze it, and interpret it for the goal of creating a vehicle that best meets the challenge criteria) **Using Mathematics, Information and Computer Technology, and Computational Thinking** (students measure and compare their measurements to the whole class, they develop mathematical models for measuring, they sketch changes in motion and graph motion data, they create symbolic representations of forces and how changes in force affect the motion of the vehicle)	Unit Level: **Systems and System Models** (representation of inputs and outputs and how energy changes in the system) Section Level: **Cause and Effect** (how changes in motion are caused based on design changes) **Stability and Change** (cause of change in motion resulting from different forces)

Vehicles in Motion: Address the Big Challenge Design and Build a Vehicle That Will Go Straight, Far, and Fast, and Carry a Load		
Storyline (with Disciplinary Core Ideas and Science Content)	**Science and Engineering Practices**	**Crosscutting Concepts**
Addressing the *Big Challenge* requires students to synthesize what they know and provide evidence for their claims. Students now apply their experiences to design and build their best vehicle that can: travel straight, travel far, travel fast, carry a load, maybe travel over one or more hills, and maybe travel over rough terrain. They are provided a track that has includes hills or rough terrain. (These choices are left to the teacher and could be an opportunity for differentiation.) This competitive challenge encourages students to build their best car given the format of the track. Students are encouraged to add or subtract weight, alter the propulsion system, change wheels, or whatever they can determine will create a vehicle that will meet the challenge and stay within the criteria and constraints of the challenge. They again use the iterative design cycle to build and test their vehicle. They then "present" their ideas by running the vehicle on the track and describing their design choices and the evidence they used to make those choices. **Disciplinary Core Ideas:** **ETS1.C: Optimizing the Design Solution** · Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (MS-ETS1-3) · The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (MS-ETS1-4)	**Constructing Explanations and Designing Solutions** (students create recommendations using gathered evidence for how to design, build, and test a vehicle that meets the design challenges, they revise their recommendations based on the data of others) **Developing and Using Models** (physical model of a vehicle is used to describe, predict, and explain motion and forces that change motion, graphical representations of motion and forces serve to help students generate predictions and explanations of forces) **Planning and Carrying Out Investigations** (using vehicle to investigate motion, working in small groups to develop and then carry out class procedures to test the effect of variables on motion) **Engaging in Argument from Evidence** (sharing data and focusing on the criteria of developing a propeller car that will go straight and far and fast and carry a load, creating claims about the group's vehicle and its motion and sharing these ideas with others) **Analyzing and Interpreting Data** (groups collect vehicle motion data, analyze it, and interpret it for the goal of creating a vehicle that best meets the challenge criteria)	Unit Level: **Systems and System Models** (representation of inputs and outputs and how energy changes in the system) Section Level: **Cause and Effect** (how changes in motion are caused based on design changes) **Stability and Change** (cause of change in motion from different forces)

Address the Big Challenge (continued)	**Obtaining, Evaluating and Communicating Information** (reading focused on forces, creating symbolic representations of forces, demonstrating frame of reference, and providing language to be used in subsequent discussions) **Asking Questions and Defining Problems** (in the context of the vehicle's motion and variables that affect motion, students ask questions about the motion of the car, forces acting on the vehicle, and how they can change motion, and define problems that are solvable to meet the challenge) **Using Mathematics, Information and Computer Technology, and Computational Thinking** (students measure and compare their measurements to those of other groups, they develop mathematical models for measuring, they sketch changes in motion and graph motion data, they create symbolic representations of forces and how changes in force affect the motion of the vehicle)	*Address the Big Challenge (continued)*