Developing and Using Science and Engineering Practices (by Lesson)

Lesson	Elements of Science and Engineering Practice(s)	Rationale
1	Ask questions that arise from careful observation of phenomena, models, or unexpected results, to clarify and/or seek additional information.	Students ask questions that can be used to investigate a phenomenon. One set of questions is developed around the changes and interactions occurring during a collision. As a class, students group their questions into similar clusters, and based on the groups of questions, students develop ideas to investigate those questions to seek further information.
1	Ask questions to determine relationships between independent and dependent variables and relationships in models.	Students organize phenomena by type of collision and color-code these based on damage vs. no damage. Students develop a set of questions around the factors and variables of objects in the system that affect the outcome of the collision. Again, as a class, students group their questions into similar clusters, and based on the groups of questions, students develop ideas to investigate those questions to seek further information.
1	Develop and/or use a model to predict and/or describe phenomena.	Students develop a model to represent visible changes they think are happening to the parts of a system as they interact in a collision.
1	Develop a model to describe unobservable mechanisms.	Students develop a model to describe unobservable mechanisms that cause the objects to change as the objects interact in a collision.
2	Collect data to produce data to serve as the basis for evidence to answer scientific questions or test design solutions under a range of conditions.	Students collect data to serve as evidence about what happens to the shape and motion of objects during collisions. They make real-time observations and determine that slow-motion observations of colliding objects provide better evidence of what happens to colliding objects while they are in contact with each other at and after the first moment of contact.
2	Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.	Students collect observations of objects colliding in different situations, leverage previous understanding about energy of objects in motion, and argue that changes in motion are caused by energy transfer between colliding objects. Students also argue that shape changes of colliding objects are the result of at least one force between the objects. Students are not expected yet to have or apply an understanding of force pairs.
3	Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.	Students analyze slow-motion videos, classroom demonstrations, and time-lapse pictures that provide evidence of what happens when one object is in a collision or makes contact with another object. They use their analysis of these different phenomena as evidence to support or refute a written claim regarding objects bending or changing shape in a collision up to a point.
4	Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation.	In this lesson, students conduct an investigation in which they coordinate application of varying amounts of force to different materials and make observations about the resulting amount of deformation. Their observations serve as the basis for evidence to determine if the type or thickness of material affects how much it deforms when a force is applied to it.

Lesson	Elements of Science and Engineering Practice(s)	Rationale
4	Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships.	In this lesson, students construct graphs, analyze and interpret their own data, and compare their graphs and trend lines to those of other students and data from other materials tests. Students compare the trends in their graphs to those that engineers made for other materials and determine that an object with a force applied to it will result in a graph with two regions of change and resulting deformation: an elastic response (a linear region) and a response where the object permanently deforms and then eventually breaks (a nonlinear region).
4	Compare and critique two arguments on the same topic and analyze whether they emphasize similar or different evidence and/or interpretations of facts.	This lesson supports students' ability to compare and critique two arguments about the relationships among the amount of force applied to an object, the type and thickness of an object's material, and the amount an object will deform as a result of the applied force. Students consider whether the arguments emphasize similar or different interpretations of evidence from their investigations and evidence from reading about the elastic behavior of metals, rubber, wood, and diamond.
4	Respectfully provide and receive critiques about one's explanations, procedures, models, and questions by citing relevant evidence and posing and responding to questions that elicit pertinent elaboration and detail.	Students plan for reciprocal sharing and respectful critique of explanations with a peer. Students plan for how they will use evidence to explain their own thinking, listen to the explanation of their peers, pose and respond to questions that elicit pertinent elaboration and detail, and provide respectful feedback.
5	Develop and/or use a model to predict and/or describe phenomena.	Students will develop and use free body diagrams to represent how the contact forces on two different objects in a system compare when those objects collide.
5	Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation.	Students will collaboratively plan and carry out an investigation to gather evidence to explore how the peak forces between objects with different speeds and masses in a collision will compare.
6	Apply scientific ideas, principles, and/or evidence to construct, revise and/or use an explanation for real-world phenomena, examples, or events.	Students look back at the Driving Question Board and use science ideas and evidence from previous lessons to make progress on answering their questions. Students utilize their knowledge from Lesson Set 1 to determine what force and energy interactions occur to cause concussions during a real-world soccer scenario.
7	Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation.	Students conduct an investigation to produce data to serve as the basis for evidence that meets the goals of the investigation. Though there is not a lesson-level performance expectation for this practice, a suggested extension opportunity is included in day 1 of the lesson to have students evaluate the sources of error in investigation 1 and suggest ways to revise the experimental design to reduce some of those sources of error.
7	Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships.	Students construct two coordinate graphs of data they collect from a simulation. On day 2 of the lesson they analyze both graphs and interpret a linear relationship in one and nonlinear relationship in the other.

Lesson	Elements of Science and Engineering Practice(s)	Rationale
7	Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena.	Students construct an explanation in their answers that includes quantitative relationships between variables (changes in mass and speed of an object) that predict which would have a bigger effect on the damage that occurs in a collision (or whether damage would not occur at all).
8	Develop and/or use a model to predict and/or describe phenomena.	Students develop and use a model to describe where contact forces are causing energy transfer between different subsystems and objects within the larger cart-launcher system. They use the model to predict additional sources of matter the box and cart are in contact with that may be producing contact forces on them to account for where the energy in the system is transferred to explain why those objects eventually stop moving.
9	Develop or modify a model—based on evidence—to match what happens if a variable or component of a system is changed.	On day 2 of this lesson, students will work in the Scientists Circle as a class to revise their collision system model using data from their investigations. The class will add additional representations to this model to show where else contact forces are occurring and energy is being transferred in the system. In their home learning they revise their free-body diagrams for the cart and box to reflect their new understandings.
9	Collect data to produce data to serve as the basis for evidence to answer scientific questions or test design solutions under a range of conditions.	In this lesson, students will investigate how forces due to friction and air resistance affect the motion and kinetic energy of objects before collisions. They will test a range of conditions including moving carts with and without sails, analysis of data on how wind impacts fuel economy, effects of rough and smooth surfaces that slide past each other, and how rough and smooth surfaces behave at a particle level.
9	Apply scientific ideas, principles, and/or evidence to construct, revise and/or use an explanation for real-world phenomena, examples, or events.	Students will use the data they collect to develop individual explanations of what causes friction and air resistance, how these cause contact forces, and how these in turn cause energy to be transferred in the system on day 1 and will share on day 2.
9	Respectfully provide and receive critiques about one's explanations, procedures, models, and questions by citing relevant evidence and posing and responding to questions that elicit pertinent elaboration and detail.	On day 1 of this lesson, students will develop claims about the effects of friction and air resistance on the kinetic energy and motion of objects in a collision system. On day 2, students will work in feedback groups to share and defend their claims and engage in respectful and reciprocal feedback to identify the most relevant ideas they will use to revise their collision system model.
10	Apply scientific ideas, principles, and/or evidence to construct, revise and/or use an explanation for real-world phenomena, examples, or events.	Students apply evidence from activities and ideas they have developed in the first nine lessons to construct an explanation for one or two possible outcomes of a collision from the Lesson 1 Related Phenomena poster. These ideas are utilized and transferred to a new scenario to answer real-world questions about baseball in an assessment.

Lesson	Elements of Science and Engineering Practice(s)	Rationale
11	Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.	Students define the purpose of a design both as a whole class and individuals for a device of their choosing. Students design a protective device for an object of their choosing and work individually and as a class to refine criteria and constraints that are both specific to their design and also apply to all protective devices. Students determine that in order to optimize their designs, further work needs to be done to understand what scientifically makes one material potentially more protective than others.
11	Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system.	Students use prior knowledge of peak force interactions to develop a draft design of a damage-reducing device for an object of their choice.
12	Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.	Students develop a model of the structure(s) of protective materials to predict and explain how they function in a collision at the microscopic scale. Students explain how the arrangement of the structures in a material (a subsystem of the overall protective design) reduces peak forces on the protected objects.
12	Analyze and interpret data to provide evidence for phenomena.	Students reflect on class data and analyze the data to determine which materials reduced peak force on objects more than others in a collision. The data are used as evidence to support what materials to compare for observing similarities in structural patterns of the materials.
13	Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena.	Students develop a model describing the relationships among space in microscopic structures within cushioning material, the amount those structures deform in a collision, the amount of peak force they produce, and the total amount of contact time during the collision at the end of day 1 of the lesson. They also develop free body diagram models to represent the relationships among these variables on day 2 of this lesson.
13	Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena.	Students construct an explanation of how (and why) the structure of a cushioning material affects the peak forces produced in a collision in their individual Progress Tracker entry at the end of day 1 of the lesson. They use the results from the large-scale ring structure representation of those structures that relate the amount of space in microscopic structures within cushioning material available to be able to deform in a collision, the amount of peak force they produce, and the total amount of contact time during the collision at the end of day 1 of the lesson. They also develop free body diagram models to represent some of these relationships on day 2.
13	Construct an explanation using models or representations.	Students construct an explanation of how (and why) the structure of a cushioning material affects the peak forces produced in a collision in their individual Progress Tracker entry at the end of day 1 of the lesson. They use the results from the large-scale ring structure representation of those structures that relate the amount of space in microscopic structures within cushioning material available to be able to deform in a collision, the amount of peak force they produce, and the total amount of contact time during the collision at the end of day 1 of the lesson.

Lesson	Elements of Science and Engineering Practice(s)	Rationale
13	Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed world(s).	Students critically read a scientific text adapted for classroom use when they complete their home learning. They answer questions in the reading to help them determine central ideas related to how concussions and nerve cell damage (to axons of neurons) can lead to memory loss, how a snug fit for a helmet would impact its performance, and how changes in the structure of cushioning material in a helmet would affect its performance.
14	Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and re-testing.	Students redesign their protective devices based upon their science ideas and receive feedback from stakeholders to optimize their designs. In the process of reviewing the feedback and using a matrix to analyze the data in regards to the stakeholder considerations, students determine that certain trade-offs will have to be made. These trade-offs are evidenced in the prioritization of criteria to quantify the materials results in an effort to optimize the materials used in the protective device design. Students then consider the implications of these prioritizations and trade-offs on the overall function of the device.
15	Develop and/or use a model to predict and/or describe phenomena.	See Lesson 15 Teacher Reference for specific questions that are aligned to this element of this practice in the assessments.
15	Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system.	See Lesson 15 Teacher Reference for specific questions that are aligned to this element of this practice in the assessments.
15	Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and re-testing.	See Lesson 15 Teacher Reference for specific questions that are aligned to this element of this practice in the assessments.
16	Communicate scientific and/or technical information (e.g. about a proposed object, tool, process, system) in writing and/or	Students develop an oral presentation to communicate information about their proposed design solution's ability to better protect objects based upon the scientific information gained in Lesson Set 3 around structures of different cushioning materials, peak forces, and trade-offs made when designing devices for protection.

Developing and Using Crosscutting Concepts (by Lesson)

Lesson	Elements of Crosscutting Concept(s)	Rationale
1	Cause and effect relationships may be used to predict phenomena in natural or designed systems.	Students consider on slide G a variety of causes (variables or factors) that contribute to damage to objects in a collision. These variables and factors will include characteristics of objects in the system before they make contact, which includes mass, speed, material type, and so forth. The factors and variables identified could potentially have an effect on the behavior of the object in a collision and cause damage or no damage to occur. Students ask questions about the effects of these variables on an object that cause it to have damage or no damage.

Lesson	Elements of Crosscutting Concept(s)	Rationale
1	Models can be used to represent systems and their interactions—such as inputs, processes andoutputs—and energy, matter, and information flows within systems.	Students model a system where two objects are colliding and consider nonvisible interactions. These interactions may include inputs and outputs between objects in the collision, such as energy or forces. In all cases, students may also be considering changes occuring in the matter of the object, both macroscopically and at a particle level.
1	Stability might be disturbed either by sudden events or gradual changes that accumulate over time.	Students consider what visible, intermediate changes might happen between two time points in collisions that result in two different outcomes: no damage and damage (stability and permanent change).
2	Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation.	Students use evidence to argue cause and effect mechanisms about what causes changes in the motion and shape of colliding objects. Students will argue that energy transfers cause changes in motion of colliding objects and that at least one force causes changes in shape of colliding objects. Students are not expected yet to have or apply an understanding of force pairs.
2	Phenomena that can be observed at one scale may not be observable at another scale.	Students encounter challenges as they investigate what happens during collisions by dropping rigid objects on fragile targets. They determine that observations using slow-motion video provide better data for determining changes in the motion and shape of colliding objects while they are in contact with each other at and after the first moment of contact.
2	Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems.	Students investigate and try to make sense of changes in motion and shape for objects in the colliding cart systems in day 2 of the lesson. Students will begin to refer to the objects in the collision as belonging to subsystems (attached to carts) whose motion changes within the larger system due to the collision. This systems thinking and reference to subsystems that the colliding objects are connected to is used in the representations the class develops for the consensus model at the end of the lesson.
2	Within a natural or designed system, the transfer of energy drives the motion and/or cycling of matter.	Students argue for representing the transfer of energy between a moving and a stationary object in a collision to account for changes in kinetic energy in both objects in the consensus model they develop together as a class at the end of the lesson.
3	Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales, including the atomic scale.	Students use slow-motion video to observe collision events that occur over a short period of time (e.g., baseball hitting bat) and use a timelapse video to observe increasing amounts of contact force applied over a longer period of time (on a concrete joint). Students observe that all objects deform when forces are applied, even if the deformation could not be seen in real time (a false perception of stability), and when the force is removed, some of those objects can still return or rebound to their original shapes, while others change deform permanently (e.g., fracture or break into pieces).

Lesson	Elements of Crosscutting Concept(s)	Rationale
4	Graphs, charts, and images can be used to identify patterns in data.	This lesson supports students in looking for patterns in graphs, charts, and data that can be used to identify cause and effect relationships among the amount of applied force, the type and thickness of a material, and the amount of deformation resulting from the applied force. Students collect their own data about how much applied force causes different materials to deform permanently or temporarily. They also look at data about the elastic behavior of metals, rubber, wood, and diamond.
4	Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales, including the atomic scale.	Students examine the relationship between forces and type of deformation in an object. Students measure this in materials they test themselves on day 1. They graph their data and compare their graphs to data collected by other students and engineers to identify two regions of change in an object: an elastic region (which can be considered a relatively stable response) and a region where the object permanently deforms and eventually breaks (a relatively unstable response).
5	Patterns can be used to identify cause and effect relationships.	Students use the patterns they observe in the peak forces detected on two different objects in an investigation they plan and carry out to identify that the cause for an increase in the magnitude of both peak forces was an increase in the independent variable they manipulate (either the mass or the speed of a moving object before a collision).
5	Models can be used to represent systems and their interactions—such as inputs, processes andoutputs—and energy, matter, and information flows within systems.	Students develop a system model together as a class to represent relative differences in the kinetic energy of a moving object that has more mass or more speed and the related peak force interactions that emerge in a collision between that moving object and a stationary one. Students develop models (free body diagrams) to represent the contact forces on two different subsystems (the two colliding objects).
5	Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales, including the atomic scale.	Students develop a free body diagram to represent the contact forces on two different subsystems (the two colliding objects). In these diagrams students represent aspects of the forces that are always constant, such as there always being two forces, each on a separate object, each acting in an opposite direction, and each having equal strength. They also represent the one aspect of the forces that changes as the kinetic energy of the object involved in a collision changes (due to changes in the mass or speed of that object). That aspect is the magnitude of the forces, which they represent with changes in the length of the forces arrows.
6	Cause and effect relationships may be used to predict phenomena in natural or designed systems.	In the lesson assessment students compare different soccer collisions to determine which collision would cause a greater peak force and transfer of energy to affect the structure of the brain and cause damage.
6	Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales, including the atomic scale.	In the lesson assessment students utilize their ideas of force pairs, peak forces, and kinetic energy to explain how different observable soccer collisions can affect the stability of an axon and cause changes to the structure of the brain (damage) during a collision.

Lesson	Elements of Crosscutting Concept(s)	Rationale
7	Patterns in rates of change and other numerical relationships can provide information about natural and human designed systems.	Students analyze patterns in tabular data to determine rates of change and scale factors among increases in speed, increases in mass, and the corresponding increase in kinetic energy.
7	Graphs, charts, and images can be used to identify patterns in data.	Students graph data gathered from a simulation to determine patterns in the relationship among speed, mass, and the amount of kinetic energy an object has, measured in terms of how far that object pushes against another object until both objects come to a stop. They analyze these graphs to identify which patterns are linear (mass vs. kinetic energy) and which ones are not (or nonlinear) (speed vs. kinetic energy).
7	Proportional relationships (e.g., speed as the ratio of distance traveled to time taken) among different types of quantities provide information about the magnitude of properties and processes.	Students analyze changes in mass and speed and the corresponding amount of kinetic energy that a moving object has and determine scale factors to describe how much the *y* values (energy) change in relation to the corresponding *x* values (mass or speed). Examples include determining that doubling the mass of a moving object results in double the amount of kinetic energy it has, while doubling its speed results in a quadrupling the amount of kinetic energy it has.
8	Cause and effect relationships may be used to predict phenomena in natural or designed systems.	Students identify places where contact forces are causing energy transfer between different subsystems and objects within the larger cart-launcher system. They do this as a class. They describe these places as where the hand makes contact with the cart and launcher, where the spring plunger makes contact with the cart, and where the cart makes contact with the box. They do this individually as well, brainstorming additional sources of matter the box and cart are in contact with that may be producing contact forces on them to account for where the energy in the system is transferred to explain why those objects eventually stop moving.
8	Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems.	Students identify subsystems and objects interacting with each other within the larger cart-launcher system to account for where contact forces are causing energy transfer to happen.
8	The transfer of energy can be tracked as energy flows through a designed or natural system.	Students track the flow of energy through a designed system (the cart-launcher, track, and box apparatus from the previous lesson) when they develop a consensus model for how energy is transferred into the system, where it is stored before releasing it, and how it is transferred from the launcher to the cart and from the cart to the box. Students brainstorm additional sources of matter the box and cart are in contact with that may be producing contact forces on them to account for where the energy in the system is transferred to explain why those objects eventually stop moving.
9	Macroscopic patterns are related to the nature of microscopic and atomic-level structure.	To better understand how friction affects kinetic energy and motion of objects in a collision system, students will examine microscopic images of rough and smooth surfaces that slide past each other. They will also use a computer interactive to understand changes at the particle level of surfaces that experience forces due to friction.

Lesson	Elements of Crosscutting Concept(s)	Rationale
9	Cause and effect relationships may be used to predict phenomena in natural or designed systems.	Students will use evidence and observations collected in investigations on day 1 to develop an explanation about the causes for changes in kinetic energy and motion of objects in a collision system.
9	The transfer of energy can be tracked as energy flows through a designed or natural system.	On day 2 of this lesson, the class will work together to update their collision system model and track energy flows through the system. Specifically they will account for energy changes due to two contact forces--friction and air resistance--at different points in time.
10	Cause and effect relationships may be used to predict phenomena in natural or designed systems.	Students use the idea that an increase to the mass, speed, or kinetic energy of an object can be used to predict an increase in peak forces exchanged during a collision and can be used to predict greater damage during the interaction. A reduction of these factors can aid in the reduction of damage produced in the system. On the lesson assessment students determine the overall effects of the changes in ball pitch speed due to air resistance, interpret data to determine the effects of mass increases of bats on ball speed, and determine the effect of deformation on a bat and ball system that contributes to a warning label on titanium bats on the lesson assessment.
10	Models can be used to represent systems and their interactions—such as inputs, processes andoutputs—and energy, matter, and information flows within systems.	Students create a diagram and include relevant energy changes to the system to explain why some collisions would result in damage and others in no damage. Energy in a collision is shown to be equal and opposite, like the force pair interactions, during the collision, and increased energy levels before the collision result in a larger exchange of energy during the collision between parts of the system. Changing the kinetic energy of an object before the collision affects the damage potential of the object. These ideas are applied in the assessment as students use the flow of energy from one system to another to explain a decrease in ball speed due to air resistance, the effects of increasing bat mass and speed on the kinetic energy in the system, and the effects of deformation on a titanium bat-ball system interaction.
10	Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales, including the atomic scale.	Students explain on the assessment how the kinetic energy of a baseball is affected by collisions with microscopic air particles over a long distance, which apply a small amount of force to the ball, leading to a decrease in the overall amount of kinetic energy for that object (quantified by ball speed).
11	Complex and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the shapes, composition, and relationships among its parts; therefore, complex natural and designed structures/systems can be analyzed to determine how they function.	Students zoom in on the main protective material that is being used in their design. Students attempt to justify what scientifically makes this material the best choice to protect their object, separating the force interactions of the subsystem in order to understand its impact on larger, whole-system interactions.
11	Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.	While developing a protective device design, students consider the properties of different materials and weigh the trade-offs for selecting different materials. Students must determine an object's shape and justify their choices based upon given criteria and constraints.

Lesson	Elements of Crosscutting Concept(s)	Rationale
12	Graphs, charts, and images can be used to identify patterns in data.	Students compare peak force reduction materials results from testing ten different materials, summarized in a class summary chart. They inspect zoomed-in images of the microscopic structures of the materials. Students identify that the materials that reduce peak forces the most have patterns in their structure composition, including air gaps or pockets and the ability to deform when a contact force is applied.
12	Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.	Students analyze structures of materials that data have shown reduce peak forces in a collision to determine similarities in their properties. The properties of these materials will then be applied in future lessons to better design a device that reduces peak forces on objects students wish to protect.
13	Macroscopic patterns are related to the nature of microscopic and atomic-level structure.	Students recognize that macroscopic patterns are related to the nature of small and microscopic structures in the discussions at the start of day 1 when the class co-constructs the Smaller-Scale Material Structures poster. Students argue that the large-scale ring structures to understand changes happening in contact time and space (amount of deformation) in different small and microscopic cushioning structures in day 1 of this lesson before analyzing the videos. They apply what they figured out at a macroscopic scale to explain what is happening at a microscopic scale in their individual Progress Tracker entries at the end of day 1 of this lesson.
13	Grades 3-5: A system can be described in terms of its components and their interactions.	Students use large-scale ring structures to understand changes happening in contact time and space (amount of deformation) in different small and microscopic cushioning structures in day 1 of this lesson. They apply what they figured out at a macroscopic scale to explain what is happening at a microscopic scale in their individual Progress Tracker entries at the end of day 1 of this lesson.
13	Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems.	Students develop free body diagrams to represent the contact forces on three (or more) different subsystems (the two colliding objects and the cushioner structure[s] between) when they complete one part of a handout with a partner and the last part alone. The choice of how many subsystems to divide the cushioning structure into is up to students.
13	Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.	Students analyze many complex natural and designed structures and systems to determine how they function in all their ring-shape investigations in this lesson. They extend this work in their out-of-class reading when they interpret diagrams on the structure of a bike helmet and answer questions about how changes to its structure would affect its function. They also engage in the use of this crosscutting concept when they connect the structure and function of neurons (in the reading) to the role they have in storing memories and how this can be damaged in concussion.

Lesson	Elements of Crosscutting Concept(s)	Rationale
13	Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales, including the atomic scale.	Students develop free body diagrams to represent the contact forces on three (or more) different subsystems (the two colliding objects and the cushioner structure[s] between). In these diagrams students represent aspects of the forces that are always constant, such as there always being two forces, each on a separate object, each acting in an opposite direction, at each point of contact, and each having equal strength. And they represent the relative strength difference in these forces compared to peak forces for other structures by shortening or lengthening the force arrows represented in each free body diagram.
14	Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.	Students consider the ability of certain materials to meet specific stakeholder considerations based upon their material properties. Students use data to cross reference the usability of different materials with other materials to make an informed design decision for the proposed function of the device.
15	Cause and effect relationships may be used to predict phenomena in natural or designed systems.	See Lesson 15 Teacher Reference for specific questions that are aligned to this element of this crosscutting concept in the assessments.
15	Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems.	See Lesson 15 Teacher Reference for specific questions that are aligned to this element of this crosscutting concept in the assessments.
15	Models can be used to represent systems and their interactions—such as inputs, processes andoutputs—and energy, matter, and information flows within systems.	See Lesson 15 Teacher Reference for specific questions that are aligned to this element of this crosscutting concept in the assessments.
15	Complex and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the shapes, composition, and relationships among its parts; therefore, complex natural and designed structures/systems can be analyzed to determine how they function.	See Lesson 15 Teacher Reference for specific questions that are aligned to this element of this crosscutting concept in the assessments.
15	Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.	See Lesson 15 Teacher Reference for specific questions that are aligned to this element of this crosscutting concept in the assessments.
15	Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales, including the atomic scale.	See Lesson 15 Teacher Reference for specific questions that are aligned to this element of this crosscutting concept in the assessments.
15	Small changes in one part of a system might cause large changes in another part.	See Lesson 15 Teacher Reference for specific questions that are aligned to this element of this crosscutting concept in the assessments.
16	Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.	Students develop a presentation to communicate to investors how the structures of various materials are manipulated into specific shapes to meet the intended purpose or function of providing protection to an object of their choice.