

| Why do things sometimes get damaged when they hit each other?  **Contact Forces: Collisions**    **OpenSciEd Unit 8.1** |
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| Unit Development Team Michael Novak, Unit Lead, Northwestern University  Susan Kowalski, Field Test Unit Lead, BSCS Science Learning  Zoë Buck Bracey, Writer, BSCS Science Learning  Joel Donna, Writer, University of Wisconsin - River Falls  Shelly Ledoux, Writer, The Dana Center at University of Texas - Austin  Dawn Novak, Writer and Reviewer, BSCS Science Learning  Whitney Smith, Writer, BSCS Science Learning  Tara McGill, Review, Northwestern University  Christina Schwarz, Unit Advisory Chair, Michigan State University  Thomas Clayton, Teacher Advisor, Columbia Middle School, Berkeley Heights, NJ  Amanda Leighton, Teacher Advisor, Haddonfield Middle School, Haddonfield, NJ  Katie Van Horne, Assessment Specialist Production Team BSCS Science Learning   * Stacey Luce, Editorial Production Lead and Copyeditor * Valerie Maltese, Marketing Specialist & Project Coordinator * Renee DeVaul, Project Coordinator * Chris Moraine, Multimedia Graphic Designer | OpenSciEd James Ryan, Executive Director  Sarah Delaney, Director of Science  Matt Krehbiel, Director of Outreach Developers Consortium Leadership Daniel C. Edelson, Director  Audrey Mohan, Associate Director  Professional Learning Center at Boston College   * Katherine McNeill, Director * Renee Affolter, Assoc. Director   Instructional Materials Center at BSCS Science Learning   * Daniel C. Edelson, Director * Audrey Mohan, Assoc. Director   Field Test Implementation and Evaluation Center at Charles A. Dana Center, The University of Texas at Austin   * Carolyn Landel, Director * Sara Spiegel, Assoc. Director, Implementation * Carol Pazera, Assoc. Director, Evaluation   Field Test Evaluation Center at Digital Promise   * Andrew Krumm, Director * William Penuel, University of Colorado, Boulder, Co-Director   Instructional Materials Center at Northwestern University   * Brian Reiser, Director * Michael Novak, Assoc. Director | State Steering Committee California   * Kathy DiRanna * Jill Grace * Phil Lafontaine * Susheela Valdez   Iowa   * Tami Plein   Louisiana   * Jill Cowart * Lydia Hill * Tana Luther * Breigh Rhodes * Molly Talbot   Massachusetts   * Erin Hashimoto-Martell * Hillary Paul Metcalf * Nicole Scola   Michigan   * Mary Starr   New Jersey   * Michael Heinz   New Mexico   * Yanira Vazquez * Shafiq Chaudhary   Oklahoma   * Megan Cannon * Tiffany Neill * Susan Wray   Rhode Island   * Erin Escher * Carolyn Higgins * Phyllis Lynch * Kate Schulz   Washington   * Ellen Ebert |
| --- | --- | --- |

### Field Test Teachers

| California Diana Campos  Will Carter  Patrick Chan  Ali Gubary  Matt Newcomb  Celina Register Iowa Abby Richenberger  Kira VanWinkle | Louisiana Mandi Adams  Andrea Ambrew  Kelly Birdsong  Darlene Brown  Mallory Cavin  Arkishia Chocklin  Nicole Lynch  Holly Orgeron  Allison Rhodes  Carrie Trotti  Holly Ward  Katie Wilcox | Massachusetts Maria Citrin  Michael Clinchot  Alice Elbakian  Ann Finkel  Rachel Harris  Charles (Chuck) Hickey  Mary Holland  Johanna Mendillo  Jamie Mitchell  Roselynn Rodriguez | Michigan Lisa Beckman  Sarah Bowman  Patsy Curnell  Shelley Jackson  John Lange  Lisa Luke  Julia Maceri  Michelle Scarborough  Leslie Buzzy  Scott Wheeler New Jersey Thomas Clayton  Jessica Herrera  Ian Levine  Dan Mazol  Andrea Poppiti | New Mexico Alexander Baca  Heather Farnsworth  Dave Layman  Jason McKinney  Mark Palmer  Naina Panthaki  Brayden Price  Sigurd Schmitz  Hannah VanScotter Oklahoma Lori Baggett  Sasha D'Andrea  Dominique Poncelet  Donna Shrier  Bryce Woltjer | Rhode Island Alisha Iafrate  Stephen Scappaticci  Kellie Sorel Washington Greg Bachmeier  Jacob Bell  Heidi Fluegel  Katie James  Victoria Wells  Kristi Young |
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### Additional Contributions

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# UNIT OVERVIEW

## Why do things sometimes get damaged when they hit each other?

This unit on contact forces begins as students consider situations in which they have seen their phones break. They contrast these situations with others where something else collided with another object and either did break or, surprisingly, did not. Attempting to identify the factors that contribute to damage occurring in some collisions and not others, as well as trying to explain what is happening during the collision that causes one type of result versus another, sparks a series of questions and ideas for investigations around the question why do things sometimes get damaged when they hit each other? This drives the work for the first two parts of the unit.

In the first part of the unit, students make general observations about what happens to objects during collisions and quickly move to analyzing data that show that objects deform when forces are applied. This leads them to

* plan and carry out investigations and analyze and interpret data to figure out that all solid objects behave elastically up to a point and that the forces between objects in a collision are always equal in size and opposite in direction.
* develop and use free body diagram models to represent the changes in the relative strength of forces on different objects in a collision.
* create and use mathematical models to determine how changes in the mass and speed of an object affect the amount of kinetic energy that object has.
* develop and use system models to support explanations for how contact forces, including friction and air resistance, cause energy to be transferred from one part of the system to another before, during, and after a collision.

In the second part of the unit students design solutions to protect an object of their choice in a collision. They gather design input from stakeholders to refine the criteria and constraints for their design solution, and the class works together to carry out a series of investigations to answer the questions they have about optimizing their design solutions. This leads them to

* plan and carry out investigations to determine which cushioning materials reduce peak forces the most in a collision.
* develop macroscopic models of small and microscopic structures of these materials and use these to generate data about how space to deform, contact time in a collision, and peak forces in a collision are related.
* carry out investigations and analyze data about how the shape and size of cushioning materials affect force distribution in a cushioning structure.
* identify trade-offs, analyze and critique design solutions, and optimize designs solutions using evidence from these investigations to solve different design problems for different stakeholders and different contexts.

The final part of the unit re-anchors around a related question and a design problem to figure out what kinds of solutions we can design to protect fragile things from breaking.

## Building Toward NGSS Performance Expectations

MS-PS2-1:

Apply Newton’s Third Law to design a solution to a problem involving the motion of two colliding objects.

MS-PS2-2:

Plan an investigation to provide evidence that the change in an object’s motion depends on the sum of the forces on the object and the mass of the object.

MS-PS3-1:

Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.

MS-LS1-8:

Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories.

MS-ETS1-2:

Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3:

Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

| UNIT STORYLINE **Unit Question: Why do things sometimes get damaged when they hit each other?** | **Phenomena legend** |
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| Lesson Question | Phenomena or Design Problem | What we do and figure out | How we represent it |
| --- | --- | --- | --- |
| **LESSON 1**  3 days  **What happens when two things hit each other?**  Anchoring Phenomenon | A smartphone with a cracked screen is lying on a wooden surface. The cracks radiate from a central point near the bottom half of the screen.  *Millions of phones are damaged a year in our country, and many of us have experienced such damage firsthand. We have a lot of experiences where a collision between two objects causes damage and also experiences where it surprisingly does not.* | We model what we think might happen at the moment of impact and a split second after a collision where something breaks and a collision where something doesn’t break. We consider some of the factors that could have made a difference in the outcomes of these collisions. This motivates us to create a Driving Question Board (DQB) and brainstorm possible investigations we could do in order to answer our questions. We figure out:   * In a collision between two objects, the objects have to come into contact; sometimes something is damaged, but not always. * Different factors and variables may cause objects to be damaged or not damaged in a collision. | |  | OP.CF.L1.003 |  | | --- | --- | --- | |
| **⇓ Navigation to Next Lesson:** We have a lot of questions about what happens during a collision, so we are wondering if we can look more closely at what happens when different kinds of things collide. | | | |
| **LESSON 2**  2 days  **What causes changes in the motion and shape of colliding objects?**  Investigation | OP.CF.L2.016  *In collisions between different objects like balls, CD cases, rice noodles, wooden stirrers, crackers, and carts with metal hoops, rubber stoppers, and clay on them, the shape of the objects and/or their motion changes.* | We explore colliding objects and record observations about changes in their motion and shape. We analyze slow-motion videos of some of these collisions. We develop a model to represent what we know about energy transfer and forces occurring in collisions when we see changes in motion of objects, shape of objects, or damage to objects. We figure out:   * A collision can cause the objects involved to change motion and/or change shape. * Energy transfer occurs during a collision. * There is a force(s) between objects when they make contact during a collision. | OP.CF.L2.009 |
| **⇓ Navigation to Next Lesson:** We aren’t sure if all objects, especially really rigid ones, change shape during collisions. We need more evidence and think making observations of slow-motion video of rigid objects colliding would help us determine whether this is happening or not. | | | |
| **LESSON 3**  1 day  **Do all objects change shape or bend when they are pushed in a collision?**  Investigation | Two cars traveling close together on a road. The first car is only a few feet in front of the second car behind it. Both have yellow wheel accessories and small circular stickers on the body.  *Cars, golf balls, baseball bats, and baseballs visibly bend and change shape during collisions. A piece of glass and concrete also bend when something else pushes on them.* | We make a claim about whether all solid objects bend or not when pushed during a collision. We analyze slow-motion videos, carry out an investigation with a laser and a mirror, and analyze images from a timelapse concrete joint load testing video. We argue for whether our original claims are supported or refuted by the evidence. We figure out:   * All solid objects bend or change shape in a collision and when other contact forces are applied to them. |  |
| **⇓ Navigation to Next Lesson:** Though we figured out that all solid objects deform, we are wondering how much force it takes to deform any solid object, and we started brainstorming ideas about how we could go about investigating this. | | | |
| **LESSON 4**  2 days  **How much do you have to push on any object to get it to deform (temporarily vs. permanently)?**  Investigation | Two bricks placed six inches apart. A thin wooden rod is suspended between the two bricks. A spring scale is touching the middle of the wooden rod.  *All materials have an elastic limit and will deform and return to their original shape in response to an applied force up to a point, beyond which permanent deformation occurs.* | We plan and carry out an investigation to look at the relationship between contact force applied and the amount of deformation that occurs in different materials. We construct graphs of our data and compare them to those from other materials tests. We develop a model to represent the elastic and inelastic behavior of all solid objects in response to varying amounts of force applied to them. We figure out:   * All solid objects deform elastically when force is applied to them, up to a point. * Different objects have a different elastic limit, which is the maximum amount of deformation they can withstand, beyond which they will deform permanently. * Different objects have a different breaking point, which is the maximum amount of deformation they can withstand, beyond which they will crack or split apart. * The type of material, the shape, and the thickness of an object all affect (a) how much it deforms when a force is applied to it, (b) its elastic limit and, (c) its breaking point. | OP.CF.L4.017 |
| **⇓ Navigation to Next Lesson:** Though we figured out that all solid objects elastically deform up to a point when forces are applied to them, we aren’t really sure which objects are getting pushed on when one object is moving into a stationary object in a collision. | | | |
| **LESSON 5**  2 days  **How does changing the mass or speed of a moving object before it collides with another object affect the forces on those objects during the collision?**  Investigation | A pair of hands are clasped together with pointer fingers of each hand putting pressure against the other one.  *When one of two objects (fingers or spring scales) is pushed against another of these objects, both objects deform. The peak force registered on a spring scale is the same as the peak force registered on another spring scale when they make contact with each other (either through a static load or during a collision).* | We carry out investigations to explore the strength of forces between two objects when they collide. We plan and carry out an investigation about how different speeds and masses of objects affect the amount of peak force on each object. We develop and use a model to represent the relationship between the energy of a moving object and the strength of the peak forces from a collision. We figure out:   * Objects in contact with each other apply equally strong forces on each other in opposite directions. * Objects that collide apply an equally strong peak force (maximum force) on each other during the collision. * A free body diagram can help represent the forces on the objects in a collision by considering each object separately. * Increasing the speed or mass of a moving object increases its kinetic energy (KE). * The more KE that objects in a system have, the higher the peak forces they can produce in a collision. | OP.CF.L5.020 |
| **⇓ Navigation to Next Lesson:** We have a model that we think can be used to explain why some objects break and others don’t in a collision. We want to test the use of this model on some of our initial questions and try to explain some new and related phenomena. | | | |
| **LESSON 6**  1 day  **What have we figured out about objects interacting in collisions? How can we apply our new learning to answer questions about objects interacting in collisions?**  Putting Pieces Together, Problematizing | Two soccer players compete for a header mid-air on a field. One wears a white jersey and red socks, while the other wears a green and black jersey. A group of spectators watches from the stands in the background.  *Soccer is becoming more and more popular in the United States. And while other soccer-related injuries are happening less frequently, youth soccer players in the United States are experiencing more concussions.* | We look back at questions from our Driving Question Board and answer questions we have made progress on during Lesson Set 1. We take an assessment to apply our science ideas to a new context and determine we need to figure out what causes more damage and energy transfer during a collision--increases in mass or increases in speed. We figure out:   * We have made progress on many of our DQB questions. * We can apply our learning to answer questions about peak forces, damage, and kinetic energy of moving objects in soccer collisions. | Stick figure of a soccer player heading a ball, labeled moment of peak force. Two free body diagrams show arrows: one for the player with peak force from the ball on the head, and one for the ball with peak force from the head on the ball. |
| **⇓ Navigation to Next Lesson:** During our discussion of assessment question 6, we discover we have conflicting ideas of what would cause more damage, increases in the mass or increases in speed of a moving object. We plan to investigate this further in our next lesson. | | | |
| Lesson Question | Phenomena or Design Problem | What we do and figure out | How we represent it |
| **LESSON 7**  2 days  **How much does doubling the speed or doubling the mass affect the kinetic energy of an object and the resulting damage that it can do in a collision?**  Investigation | OP.CF.L7.001  *Changes in the mass and speed of a cart affect how far it pushes a box down a track and the amount of damage it does to a cracker it runs into.* | We carry out an investigation to determine how doubling the speed of an object vs. doubling its mass affects the amount of damage it does in a collision. We analyze data to determine how to quantify the relative change in the kinetic energy of an object. We use a computer simulation to collect additional data on changes in the mass and the speed of a moving object and the amount of kinetic energy. We develop mathematical models of these relationships and use them to predict and explain how this could affect the amount of damage in a collision. We figure out:   * In an investigation with multiple independent variables it is important to keep track of which variables are remaining constant and which are changing * The more kinetic energy an object has the more damage it can do in a collision. * The more kinetic energy an object has the more you have to push against the direction of its motion to get it to stop. * The kinetic energy of an object is directly proportional to its mass; the KE of an object is proportional to the square of its speed. | OP.CF.L7.010 |
| **⇓ Navigation to Next Lesson:** We have some initial ideas and some specific questions about where the energy is coming and where it is going in our cart-launcher system before and after the cart collided with a cracker or a box. | | | |
| **LESSON 8**  1 day  **Where did the energy in our launcher system come from, and after the collisions where did it go to?**  Investigation | A black sneaker with white laces and a scuffed white rubber toe cap is placed on a wooden floor. There is a rubber band attached to the shoelaces closest to the toe. The rubber band is pulling the laces toward to the toe. A silver metal ruler shows the length between laces and the end of the shoe is 2 inches.  *A phenomena from the previous lesson: Pulling back a cart against a push-pull spring scale and releasing it results in it launching the cart down a track, the cart running into a box, and the box getting pushed some distance down the track by the cart until both the cart and box stop moving.* | We develop a model to show where energy is transferred between the spring, cart, and box and how contact forces cause this energy transfer. We use this to start brainstorming other places where contact forces may be causing energy transfer in the system. We figure out:   * The more force you apply to an object the more that object speeds up. * It takes more force to speed up a more-massive object the same amount as a lower-mass object. * Potential energy can be stored in some systems when you change the shape or arrangement of parts in that system (e.g., a spring). * Contact forces transfer energy between different objects or subsystems within the larger cart-launcher system. | |  | OP.CF.L8.012 |  | | --- | --- | --- | |
| **⇓ Navigation to Next Lesson:** We have some ideas about other places where contact forces may be causing energy transfer in the system and we want to investigate two of these types of interactions further: sliding along the track surface and moving through the air. | | | |
| **LESSON 9**  2 days  **How do other contact forces from interactions with the air and the track cause energy transfers in the launcher system?**  Investigation | OP.CF.L9.002  *An index card on the front of a cart visibly deforms when the cart coasts down the track; it deforms more when a faster headwind is blowing toward it; the cart doesn’t travel as far and its direction of motion reverses in a headwind.* | We conduct investigations to gather evidence to explain what other forces affect the kinetic energy of an object before a collision. We develop claims using our evidence and provide and receive feedback with peers to synthesize our ideas. We revise our model to show additional places in the launcher system where energy is transferred and how contact forces cause this energy transfer. We figure out:   * Friction is a contact force due to interaction between surfaces in contact and is produced by the bumps (roughness) on surfaces as they push against each other. * Interactions due to friction and air resistance apply contact forces to a moving object that are in a direction that is opposite its motion. * Force interactions due to friction and air resistance transfer energy to the surfaces of the objects that slide over each other; this results in an increase in particle-level kinetic energy (a temperature increase). * Energy can be transferred to and from collisions between objects and particles in the air. | OP.CF.L9.012 |
| **⇓ Navigation to Next Lesson:** We know a lot about how damage occurs and we want to explain why some objects break and others don’t in collisions. | | | |
| **LESSON 10**  2 days  **Why do some objects break or not break in a collision?**  Putting Pieces Together | Warning sign advising that balls hit with a titanium bat may travel faster, reducing reaction time for defensive players. It urges users to warn others when using the bat to prevent injuries.  *At each level of organized baseball, there are rules in place about what type of bat and ball can be used to ensure the game play remains competitive, fair, and fun. There are other factors that can impact game play that can’t be controlled, such as weather conditions, location of the stadium, and the strength of the players.* | We revisit our collision types from Lesson 1 and explain why some objects were damaged and others weren’t in different collisions. We use these ideas to answer questions on the Driving Question Board and take an assessment to apply our new ideas to a new set of collision-related phenomena in the context of baseball. We figure out:   * We have made progress on our DQB questions. * We can apply our new learning over mass, speed, peak forces, and energy transfer to explain equipment-related collisions and interactions in baseball. |  |
| **⇓ Navigation to Next Lesson:** We can use our science ideas to answer a lot of questions about what causes damage in a collision, but we still can’t explain how certain materials seem to protect against damage better than others in a collision and we have unanswered questions about how these work. | | | |
| Lesson Question | Phenomena or Design Problem | What we do and figure out | How we represent it |
| **LESSON 11**  2 days  **What can we design to better protect objects in a collision?**  Anchoring Phenomenon | A smartphone with a cracked screen is lying on a wooden surface. The cracks radiate from a central point near the bottom half of the screen.  *All devices designed to protect objects have common criteria and constraints.* | We look back at our anchor and discover that some phones were in protective cases when they were damaged. We develop new phone case criteria and constraints and design our own protection device for something we want to protect. We receive feedback on our designs and consider what criteria and constraints all designs need to protect objects. We develop questions about our designs and ideas for investigation. We determine that we need to figure out the best damage-reducing materials. We figure out:   * All protection devices have similar criteria and constraints. * Device shape, material, and structure have something to do with protective devices reducing damage to an object. * We need to determine what makes certain materials better at reducing damage than other materials. | |  | OP.CF.L11.002 |  | | --- | --- | --- | |
| **⇓ Navigation to Next Lesson:** While we figured out that the shared criteria of materials is important, we still need to figure out what makes one material better than another at reducing damage to an object. | | | |
| **LESSON 12**  2 days  **What materials best reduce the peak forces in a collision?**  Investigation | Close-up of orange bubble wrap showing small pockets of air forming bubbles in the plastic layer.  *Materials that help to reduce peak force in a collision have similar structures, such as greater deformation abilities and air in their structures.* | We conduct an investigation to determine what easily accessible materials reduce peak force in a collision. We compare the structure of the materials and find similarities in their compositions that might affect their function. We also determine that the peak force is reduced equally on both objects, regardless of size. We try to develop a model to explain how the structures of the materials function in a collision that helps to reduce peak forces on the objects we want to protect. We figure out:   * Materials that reduce peak force have similar structures, such as air pockets or space for air, and the ability to deform when a contact force is applied; these materials reduce the peak force equally on both objects involved in the collision. | |  | OP.CF.L12.022 |  | | --- | --- | --- | |
| **⇓ Navigation to Next Lesson:** We know that the protective materials have some similar characteristics, but we are still wondering how those help reduce peak forces when a contact force is applied. | | | |
| **LESSON 13**  3 days  **How (and why) does the structure of a cushioning material affect the peak forces produced in a collision?**  Investigation | OP.CF.L13.007  *Cushioning material has repeating patterns of air or space gaps throughout its structure. Repeated chains of open-ring structures put between two colliding objects reduce the peak forces on those objects. Other changes in the arrangement of those structures also affect the forces applied to objects in the system.* | We develop a model to represent how the structures of materials compare in the top four performers for peak force reduction. We use scaled-up versions of these structures to generate data using slow-motion video about the unobservable mechanisms at work in the system. We carry out an investigation to determine how the amount of force applied to different points of a cushioning structure is affected by the shape of that structure. We figure out:   * Protective materials tend to have a lot of space (or air) for the solid materials to deform into, which makes these materials relatively easy to deform (with little force applied to them). * The thicker these kinds of materials are, the more they reduce peak forces because this increases the total time the collision takes. * Making a material more densely packed with smaller and smaller spaces does not necessarily reduce peak forces; such increased density may actually have the opposite effect. * The more you can spread the peak forces out over a larger area or over more points of contact, the less force is applied to each point of contact; this can reduce the amount of damage on the material you are trying to protect. | OP.CF.L13.039 |
| **⇓ Navigation to Next Lesson:** We started thinking about how what we have figured out could be applied to our protective device design solutions we have been working on as well as how they could be applied to another design problem we encountered earlier (protecting players' heads from concussion in a sports-related context). We are going to try to do this in the work we do across the next two lessons. | | | |
| **LESSON 14**  2 days  **How can we use our science ideas and other societal wants and needs to refine our designs?**  Putting Pieces Together | OP.CF.L14.006  *When redesigning a device, stakeholder feedback is important to consider. Each change based upon a consideration comes with a trade-off, and those trade-offs have consequences for the usefulness and purpose of the device.* | We redesign our protective devices and receive stakeholder feedback. We use the feedback and considerations to inform decisions on primary, secondary and tertiary criteria for materials in a decision matrix. We evaluate the overall scores of the materials and consider the consequences of each change made to the protective devices. We figure out:   * Most designs will not meet every criteria and constraint perfectly. * When engaging in an engineering design problem, trade-offs will occur based upon stakeholder feedback. * Some stakeholder considerations will have a higher priority than other considerations. * Every trade-off has consequences. | A screenshot of the decision tree from a handout. Top question asks about existing protective devices in use. Options lead to fields for listing devices or defining a new devices purpose. Includes red text boxes with suggestions for writing scripts for stakeholder queries. |
| **⇓ Navigation to Next Lesson:** Now that we have prioritized material choices based upon stakeholder feedback and considerations, we can draft a design brief to share the changes and consequences of those changes with stakeholders. | | | |
| **LESSON 15**  2 days  **How can we use what we figured out to evaluate another engineer’s design?**  Putting Pieces Together | OP.CF.L15.012  *Cheerleading is a sport where the participants are at risk of concussions and traditionally haven’t worn protective headgear. More recently, headgear from other sports has been used by some cheerleading squads to try to protect their members from injury. An opportunity exists to design a more-customized form of headgear that better meets the needs of this particular sport.* | We evaluate other engineers’ design solutions to protect cheerleaders from concussions in collisions using the science and engineering ideas we have figured out over the course of the unit. We design our own solution and argue how it takes into consideration the criteria, constraints, and trade-offs considered in the proposed solution. We revisit the DQB to take stock of the questions we have answered. |  |
| **⇓ Navigation to Next Lesson:** The next lesson is an optional extension for use beyond the formal end of the unit (this lesson) for classrooms that have a strong interest in building, producing, and testing physical prototypes for design solutions students have been refining on paper in the previous lessons. | | | |
| **LESSON 16**  4 days  **OPTIONAL How can we market our designs to our potential investors?**  Putting Pieces Together | Screenshot of the flowchart for determining collision force. It categorizes force from small (dropping a book) to massive (head-on crash). Includes decision tree based on object weight and travel distance, leading to four detailed action outcomes for each scenario.  *Investors want a device that is marketable and takes into consideration the needs of stakeholders. Designers need to keep these things in mind when creating a pitch presentation for investors.* | In this *optional* lesson we develop a presentation to share our design with potential investors. We have the option to create a scale prototype and test our design and/or add visual aids to our presentation. We also present our design ideas to investors. We figure out:   * Investors care about the considerations of stakeholders. * As a designer, information has to be presented in a relevant and engaging way that allows investors to see that all stakeholder considerations have been taken into account. | OP.CF.L16.002 |
| **⇓ Navigation to Next Lesson:** There is no next lesson. | | | |
| Lesson Question | Phenomena or Design Problem | What we do and figure out | How we represent it |

**LESSONS  1-16**

33 days total

# TEACHER BACKGROUND KNOWLEDGE

### Lab Safety Requirements for Science Investigations

It is important to adopt and follow appropriate safety practices within the context of hands-on investigations and demonstrations, whether this is in a traditional science laboratory or in the field. In this way, teachers need to be aware of any school or district safety policies, legal safety standards, and better professional practices that are applicable to hands-on science activities being undertaken.

Science safety practices in laboratories or classrooms require engineering controls and personal protective equipment (e.g., safety goggles, nonlatex aprons and gloves, eyewash and shower station, fume hood, fire extinguishers). Science investigations should always be directly supervised by qualified adults, and safety procedures should be reviewed annually prior to initiating any hands-on activities or demonstrations. Prior to each investigation, students should also be reminded of the safety procedures that need to be specifically followed. Each of the lessons within the OpenSciEd units includes teacher guidelines for applicable safety procedures for setting up and running an investigation as well as taking down, disposing of, and storing materials.

Prior to the first science investigation of the year, a safety acknowledgement form for students and parents or guardians should be provided and signed. You can access a model safety acknowledgement form for middle school activities at the following location: http://static.nsta.org/pdfs/SafetyAcknowledgmentForm-MiddleSchool.pdf

**Disclaimer:** The safety precautions of each activity are based in part on use of the specifically recommended materials and instructions, legal safety standards, and better professional safety practices. Be aware that the selection of alternative materials or procedures for these activities may jeopardize the level of safety and therefore is at the user’s own risk.

### Please follow these lab safety recommendations for any lesson with an investigation:

1. Wear safety goggles (specifically, indirectly vented chemical splash goggles), a non latex apron, and nonlatex gloves during the setup, hand-on investigation, and take-down segments of the activity.
2. Immediately wipe up any spilled water and/or granules on the floor as this is a slip-and-fall hazard.
3. Follow your *Teacher Guide* for instructions on disposing of waste materials and/or storage of materials.
4. Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
5. Wash your hands with soap and water immediately after completing this activity.
6. Never eat any food items used in a lab activity.
7. Never taste any substance or chemical in the lab.

Specific safety precautions are called out within the lesson using this icon and a call-out box.

# TEACHER BACKGROUND KNOWLEDGE

### What is the anchoring phenomenon and why was it chosen?

This unit uses two anchors, one to drive student questions and investigations in the first two lesson sets of the unit, and one to drive student questions and engagement in the use of engineering ideas and the iterative design process in the last third of the unit. This unit begins with students considering national statistics on the frequency and cost of cell phone breakage. Students share situations in which they have seen cell phones break. Students then contrast these situations with other situations where something else collided with another object and either did break or, surprisingly, did not break. Students then attempt to identify the factors that contribute to damage occurring in some collisions and not others, as well as try to explain what is happening during the collision that causes some items to become damaged in a collision when others are not. Students then develop a Driving Question Board (DQB) to guide future investigations.

This introduction, using a commonly broken and widely used device, allows students to engage in the investigation of ideas regarding energy and forces in a collision. The ideas of deformation and breaking point examined in Lesson Set 1 apply widely to phone use, as some collisions result in damage while others surprisingly do not. In Lesson set 2, students also have the ability to re-examine how different collisions can lead to damage or no damage on their devices.

Lesson set 3 re-anchors students thinking about the question of why some phones still break when in protective cases. They identify an object of their choice to design protection for in a collision, they define related criteria and constraints for such design solutions and they develop initial models for why their solutions would affect the outcome of a collision. Students then add new questions to their Driving Question Board (DQB) to guide future investigations.

Each OpenScied unit’s anchoring phenomenon is chosen from a group of possible phenomena after analyzing student interest survey results and consulting with external advisory panels. We also chose cell phone breakage as the first anchoring phenomenon for this unit for these reasons:

* This anchor ranked higher than the top alternative (related to bike helmets) in a pre-field release student survey.
* +80% of teenagers own cell phones, and those who don’t are around classmates who do. Nearly all students, therefore, have multiple interactions with people on a daily basis who have these devices, even if they do not own one themselves.
* A subsequent piloting of this anchor confirmed that witnessing the type of phenomena referenced in the anchor, some sort of collision that caused someone’s cell phone to get damaged, was an extremely common occurrence.
* Cell phones are devices that people commonly buy protective cases for.
* Two pre-field test pilots of the cell phone damage) anchor produced driving question boards that had a majority of the students’ questions on them and ideas for investigations to answer those questions, which were anticipated by the unit development team, and were specifically targeted in the field test version of the storyline.

 We chose a re-anchor around a design problem for an object of the students' choice for these reasons:

* One important aspect of engaging in the engineering design process, is to define what the problem is. Positioning students as the ones who define for themselves where the problem exists and what might benefit from a solution, positions them in a more genuine problem-definition context. Subsequent interviews with potential users of such a solution also provided an opportunity for students to involve community members for their perspectives to determine important criteria for their design solution.

### What are the NGSS Dimensions developed in this context?

In this unit, students develop observations about what happens to the motion and shape of objects. They develop the idea that all solid objects deform when forces are applied to them, behaving elastically up to a point and then incurring permanent damage beyond that point. Students conduct investigations into how the contact forces between objects in a collision compare. They develop and use free-body diagrams to represent the changes in the relative strength of forces in a collision. Students also develop mathematical models to represent changes in the mass and speed of an object affecting the amount of kinetic energy that object has. They unite two different perspectives (energy and forces) to develop and use system models to support explanations for how contact forces, including friction and air resistance, cause energy to be transferred from one part of the system to another before, during, and after a collision. Students then design solutions to protect an object of their choice in a collision. They gather design input from stakeholders to refine the criteria and constraints for their design solution and they carry out investigations to determine which cushioning materials reduce peak forces the most in a collision. They develop models of how these cushioning materials function using the microscopic structures of these materials. They use these models to generate data about how space to deform increases contact time and decreases overall peak forces in a collision. They use what they figure out from these investigations to identify trade-offs, analyze and critique design solutions, and optimize a design solution to solve different design problems for different stakeholders and different contexts. They apply their new understandings to different sports-related contexts (soccer, baseball, and cheerleading), in different transfer tasks over the course of the unit.

| **This unit builds toward these performance expectations:** | | |
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| **MS-PS2-1** Apply Newton’s Third Law to design a solution to a problem involving the motion of two colliding objects.  **MS-PS2-2.** Plan an investigation to provide evidence that the change in an object’s motion depends on the sum of the forces on the object and the mass of the object.  **MS-PS3-1.** Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.  **MS-ETS1-2.\*** Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.  **MS-ETS1-3.\*** Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.  **MS-LS1-8.\*** Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories. | | |
| **Focal Disciplinary Core Ideas\*\*** | **Focal Science and Engineering Practices** | **Focal Crosscutting Concepts** |
| **PS2.A. 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).** In lesson 5, students figure out that the strength of the contact forces on each of two objects in contact with each other are equal and in opposite directions of each other. This idea is reused in lesson 6-16.  **PS2.A. 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.** In lesson 7-8, students explore how increasing the strength of a force applied from a spring scale launcher to a cart affects the speed of the cart when it is launched. They figure out that after increasing the mass of the cart a larger amount of force needed to be applied to it to get it to launch at the same speed. Students determine that when greater force is applied to a constant mass, the speed of the object will increase.Students then reuse this idea in lesson 10. Students investigate net force relationships in lesson 13 to compare the strength of multiple forces applied to multiple sides of a structure when that force is being compressed but not moving.  **PS2.A. 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.** Students are introduced to frames of reference in lesson 1, when they categorize all collisions that occur in any direction into one of three categories. Students identify a reference height to measure the deformation of an object in lesson 4 and compare different units for measuring the size of a force in lesson 5. They switch between measuring forces in different scales when they record peak forces in a collision in this lesson and also in subsequent lessons.  **PS3.A. Motion energy is properly called kinetic energy ; it is proportional to the mass of the moving object and grows with the square of its speed**. Students recall their previous use of kinetic energy in the context of particle level collisions from the *Cup Design Unit* in lesson 2. In lesson 5 they identify the relative differences in kinetic energy for moving vs. non-moving carts with more or less mass or speed. In lesson 6 they gather data to determine that the kinetic energy of an object is proportional to its mass and that it grows with the square of its speed. | **Analyzing and Interpreting Data.** This unit **intentionally develops** this practice. Students work a new kind of mathematical relationship in their data analysis.  Students construct, analyze, and interpret graphical displays to identify linear and nonlinear relationships and determine that the kinetic energy of a moving object is proportional to its mass and its kinetic energy is related to the square of its speed. Students also find lines of best fit and identify quantitative relationships in their data related to the amount of deformation per Newton of force and the change in Kinetic Energy as a scale factor.  The following practices are also **key to the sensemaking** in the unit:   * Asking Questions and Identifying Problems * Developing and Using Models. * Planning and Carrying Out Investigations. * Constructing Explanations and Designing Solutions * Engaging in Argument from Evidence | **Structure and function** This unit **intentionally develops** this crosscutting concept. Students develop the idea that complex microscopic structures and systems can be visualized, modeled, and used to analyze how their function depends on the relationships among its parts in Lesson Set 3, building and testing scaled up version of the space and air cavities found in many of the most effective cushioning materials. While students will have encountered parts of this idea in the *Cup Design Unit*, this unit is the first unit that has students develop larger scale modes of microscopic structures and test them to figure out why they function the way they do.  **Stability and change.** This unit **intentionally develops** this crosscutting concept. This unit expands the scale that students consider for explanations of changes over time at different scales. Students consider forces on and within substructures that make up cushioning materials.Students also examine particle level force interactions due air resistance and surface friction to account for why the objects that were moving in a system (a cart and box) slow down, and eventually stop. |

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| **Focal Disciplinary Core Ideas\*\*** | **Focal Science and Engineering Practices** | **Focal Crosscutting Concepts** |
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| **PS3.B. When the kinetic energy of an object changes, there is inevitably some other change in energy at the same time.** In lesson 8, students develop a model to show that potential energy is stored in part of the launcher system and is transferred out of the system when the cart is launched. In lesson 9, students develop a model for showing where energy is being transferred to in the surroundings in a cart-box system.  **PS3.C. When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object.** In lesson 8 students identify contact forces as the mechanism for energy transfer in a collision. They apply this idea in lesson 9, to explain that air resistance and friction transfer energy to the surroundings due to contact force interactions between two objects or an object and many particle collisions.  **ETS1.B. There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.** **Students recall the role of criteria and constraints in design work in lesson 11.** They develop and apply a systematic process for evaluating their own design solutions in lesson 14 and 16, and for evaluating a cheerleader headgear design in lesson 15.  **ETS1.B.Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.** Students combine different aspects of material behavior to redesign their own design solutions in lesson 14 and engage in an iterative design process in optional Lesson 16 to create a protective device to meet the needs of stakeholders.  **ETS1.C. 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**. Students analyze the behavior of different materials and compare those materials to the use of materials in their own designs. Students then combine different aspects of material behavior to redesign their own solutions in lesson 14.  **LS1.D. Each sense receptor responds to different inputs (~~electromagnetic~~, mechanical, ~~chemical~~), transmitting them as signals that travel along nerve cells to the brain. The signals are then processed in the brain, resulting in immediate behaviors or memories.** Students develop this idea through a reading in lesson 5. The struck-through portion of this DCI is developed in the *One-way Mirror Unit* and *Bath Bombs Unit*. |  | The following practices are also **key to the sensemaking** in the unit:   * Patterns * Cause and Effect * Systems and System Models * Energy and Matter |

\*PEs marked with an asterisk are partially developed in this unit and shared with other units, as explained in the DCI column.

\*\*Disciplinary core ideas are reproduced verbatim from *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. DOI: https://doi.org/10.17226/13165. National Research Council; Division of Behavioral and Social Sciences and Education; Board on Science Education; Committee on a Conceptual Framework for New K-12 Science Education Standards. National Academies Press, Washington, DC. This material may be reproduced and used by other parties with this attribution. If the original material is altered in any way, the attribution must state that the material is adapted from the original.

| **Connections to the Nature of Science** | |
| --- | --- |
| Which elements of NOS are developed in the unit? | How are they developed? |
| * Science investigations use a variety of methods and tools to make measurements and observations. (NOS-SEP) | * Students use their fingers as force sensors and a peak force collar to measure the contact forces on two colliding objects, and they use a variety of materials such as a rubber band to measure the amount of friction from different surfaces and dissect various cushioning materials.  They collect data using push-pull force scales, rulers, slow motion videos, reflected laser beams, and computational  simulations. |
| **Connections to Engineering, Technology and Applications of Science** | |
| Which elements of ETS are developed in the unit? | How are they developed? |
| * Engineering advances have led to important discoveries in virtually every field of science and scientific discoveries have led to the development of entire industries and engineered systems | * Students craft an argument using science ideas regarding head injuries during sports, and evaluate new helmets for cheerleaders (an emerging need and industry). |

### How is the unit structured?

This unit is broken into three lesson sets each of which help make progress on a sub-question related to the driving question for the entire unit. Lessons 1-6 focus on developing science ideas about force interactions between colliding objects. Lessons 6-10 focus on the relationship between forces and energy transfer in collisions. Lessons 11-16 focus on design solutions to protect an object of their choice in a collision and how the structure of materials can mitigate the damage that a collision can cause.

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### Where does this unit fall within the OpenSciEd Scope and Sequence?

This unit is designed to be taught as the first unit of 8th grade. It is designed to be taught after students have experienced the *Cup Design Unit* and *Healing Unit*. As such, work in this unit can leverage ideas about the particle nature of matter, how energy can be transferred through particle-level collisions (conduction), how neurons work together to transfer signals from our senses to our brain. It is also designed to be taught after students have experienced the *Homemade Heater Unit*, as it leverages ideas about the role of criteria, constraints, stakeholders, and tradeoffs in the engineering design process.

This unit is designed to be taught prior to *OpenSciEd Unit 8.2: How can a sound make something move? (Sound Unit)*. That unit will leverage ideas about how forces transfer energy across a system and that all solid matter can be elastically deformed in a collision that are developed in this unit. It is also designed to be taught prior to *OpenSciEd Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit)*. That unit will leverage ideas about how every force is part of a force pair, that are two equal and opposite forces on two different objects.

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### What additional ideas will my students have or know from earlier grades or OpenSciEd units?

In this unit, students build upon ideas from earlier grades and the *Cup Design Unit*, *One-way Mirror Unit*, *Healing Unit*. Throughout the unit, students will build upon these previous ideas:

| **Previous unit or grade-level DCIs** | **How it is leveraged in this unit** |
| --- | --- |
| Building upon ideas developed in the *One-way Mirror Unit* and *Healing Unit* regarding **cells, receptors, and information transfer.**   * **LS1.D** Each sense receptor responds to different inputs transmitting them as signals that travel along nerve cells to the brain. The signals are then processed in the brain | In Lesson 5 students read about the sense of touch. Prior ideas about how neurons function, where they are located, and some of their structures (axon and neurons). These are leveraged in the reading to explain how we sense pain, temperature, and pressure. These ideas are also extended to help students develop a causal chain for how mechanical sense receptors in nerve cells in our skin transmit signals to other nerve cells to our brain that these signals are then processed in the brain, resulting in immediate behaviors or memories, and that, responses can be sent back from our brain to our muscles through other neurons to make them move.  In lesson 6 students work with a transfer task, that refers to the breaking point of axons in neurons related to a sports related collision context (concussions). |
| Building upon ideas developed in the *Cup Design Unit* and *Healing Unit* regarding the **particulate nature of matter and energy transfer.**   * PS 3.A Motion energy is properly called kinetic energy. * PS 3.A Temperature is a measure of the average kinetic energy of particles of matter. * PS 3.B Energy is transferred out of hotter regions or objects and into colder ones by the processes of conduction * PS 3.B When objects (and particles) collide, energy can be transferred from one object to another, thereby changing their motion | Lesson 2 elicits ideas about the way students modeled particle level motion energy from the *Cup Design Unit* and refers to it as kinetic energy. This lesson also refers to how energy transfer occurs in collisions via conduction.  Lesson 8 elicits ideas about temperature being a measure of the average kinetic energy of particles and extends ideas about energy transfer occurring through particle-level collisions to include additional interactions related to air resistance and surface friction. |
| Building upon K-5 knowledge about**forces and motion**   * PS2.A: Each force acts on one particular object and has both strength and a direction. * PS2.B When objects touch or collide, they push on one another and can change motion or shape | Lesson 2 introduces a force perspective way of considering what causes the shape of an object to change. This draws on what students should know from Kindergarten regarding what a push can do and categorizes it as a force. Students would have utilized the word force in grade 3 to describe pushes and pulls. |

This unit also leverages knowledge students may bring from their experiences outside of science class. It is valuable to think of the *relevant ideas* listed below not as misconceptions that need to be erased but as productive ideas that we can use to build understanding. Not only does this help some students feel more comfortable talking about science and build a scientific identity, it improves science learning across the board. Having a set of competing ideas to compare, evaluate, and resolve is what drives the focus of many of the lesson questions and related investigations of the unit. Students will make incremental progress on revising these ideas over multiple lessons. The list below also indicates where students will first encounter a line of evidence that they can use to start to refute these ideas.

Some *relevant ideas* about **forces** that students may come into the unit with include:

* *A force is a property of a single object rather than the result of two interacting objects.* In lesson 5, students will figure out that forces only exist in pairs.
* *In a single collision, a heavier or faster-moving object would push harder than a lighter, slower object.* In lesson 5, students will figure out that the strength of the forces in a collision is the same on both objects that make contact.
* *Only moving objects push on stationary objects, but stationary objects do not push back on the moving ones.* In lesson 5, students will figure out that stationary objects push back with the same strength of the force as the object pushing into them.
* *Inanimate objects don’t exert forces on objects that make contact with them (e.g., a hand) because they are not living.* In lesson 3, students will figure out that all objects deform when a force is applied to them. They use this idea to explain why all objects exert contact forces on each other in collisions in lesson 5.
* *Some (or all) solids are not elastically deformable. Students may have previously encountered a partial definition of a solid that is characterized as a state of matter that holds its shape (as opposed to a liquid that takes the shape of the bottom part of its container).* In lesson 4, students will collect evidence that stationary objects push back when they undergo elastic deformation.
* Some students may have heard that for any action there is an equal and opposite reaction, but they may not see that this describes what is happening at any point of contact and in any collision between two objects. They may confuse this idea with situations where the net force on an object is zero and the motion of the object isn’t changing. This is an instance of Newton’s first law, whereas the former is Newton's third law.
* Some students may have a good understanding that larger net forces are associated with larger changes in motion and that larger masses are harder to speed up or slow down than smaller masses, but students may have difficulty thinking about three variables (force, mass, and change in motion) at once.

### How will I need to modify the unit if taught out of sequence?

This is the first unit in 8th grade in the OpenSciEd Scope and Sequence. Given this placement, several modifications would need to be made if teaching this unit earlier or later in the middle school curriculum. These include the following adjustments:

* If taught before the *Cup Design Unit*, supplemental teaching of the following would be required:
* Energy transfer as the result of two colliding objects at the particle level.
* Understanding of the role of independent and dependent variables, along with controlled variables, in an investigation.
* What criteria and constraints are, and how they can be used to inform design decisions.
* If taught before the *Tsunami Unit*, supplemental teaching of the following would be required:
* What a stakeholder is, and the role of stakeholders in the iterative design process

### How do I shorten or condense the unit if needed? How can I extend the unit if needed?

The following are example options to shorten or condense parts of the unit without completely eliminating important sensemaking for students:

* Since in some ways, lesson sets 1 and 2 are anchored in explaining why sometimes get damaged when they hit each other and other don’t and lesson 3 is a re-anchor that focuses on designing protective devices for objects that we want to protect from getting damaged in a collision, one natural end point for the unit would be at the end of lesson 10, which is the end of lesson set 2.

To extend or enhance the unit, consider the following:

* **Lesson 3:** Consider letting students investigate the deformation of a table and other rigid materials in small groups using the laser setup. If this option is utilized, consider all proper safety precautions when using glass with students, such as safety goggles, gloves for potential sharp edges, and proper distribution and cleanup procedures that minimize encounters with any potential broken glass or other materials. See the materials preparation section of this lesson for more guidance.
* **Lesson 3:** Add in additional slow-motion videos in areas of student interest, such as a football making contact with the ground for classrooms that have several students engaged in football.
* **Lesson 4:** Expand the investigation to allow multiple groups to test multiple conditions. This would involve an increased number of materials and increased class time.
* **Lesson 5:** Allow students to spend more time at each investigation station. Ask students to test out each station with increased mass, increased speed, and with a variety of moving and non-moving carts.
* **Lesson 6:** Ask students to also revisit the related phenomena. Ask students to pick a related phenomena and explain the outcomes of the related phenomena (damage, no damage) using our science ideas. At this point, students should be able to construct a partial explanation for their related phenomena.
* **Lesson 10:** Ask students to once again revisit their related phenomena and attempt to explain the outcomes of the collisions. At this point, students should be able to explain the forces on each object and the energy transfer that occurs in the collision.
* **Lesson 12:** Consider allowing students to test a complete CD case in addition to a section of CD case plastic. Allow students to explain why a CD case that has space for air between the cover and backing reduces peak force more than a section of plastic.
* **Lesson 16:** Conduct the optional 16 iterative design process.
* **Lesson 16, option 2:** Expand the iterative design process by involving those from the community to share their own personal protective design issues and allow students to develop a real-world solution to a problem within the community. Consider holding a design fair where the community can explore student’s designs and offer feedback.

### What mathematics is required to fully access the unit’s learning experiences?

In general, this unit is taught using a conceptual approach to describing the relationship among force, mass, and change in motion during collisions, students need only have experience with qualitatively reasoning about positive and negative associations (e.g., as force increases, change in motion increases; but as mass increases, change in motion from a given force decreases). But because the focus of **MS-PS3-1** is on quantitative understanding of the relationship of the kinetic energy of an object to the mass of an object and to the speed of an object, students will need to leverage the following experiences from grade 7 Common Core Math Standards math to use in this unit in Lessons 7 and 10:

In lesson 7, students will be working with unit rates and ratios. By the beginning of 8th grade, students should be well versed in how to do this calculation. It will be leveraged in Lessons 7 and 10 of this unit when students recognize that the relationship between mass and kinetic energy is directly proportional. Such a relationship is one they have encountered in graphs many times in Common Core mathematics since 6th grade. Recognizing the relationship between speed and kinetic energy as nonlinear will also be straightforward. But describing the change in kinetic energy as being related to the square of the speed of an object will be challenging. Students will have encountered working with squared relationships in 6th grade in finding the surface area of a cube with sides of length *s*, and in 8th grade they will be working with squaring the side lengths of a right triangle in their work with the Pythagorean theorem. Coordinate with your math teachers to determine where you students will be at in their familiarity with thinking about relationships like these.

* In lesson 7 students calculate and use a type of ratio called a scale factor. They will use this idea again in the lesson 10 assessment and potentially again in lesson 16 as they develop a scale model of their designs. Students will have encountered this concept before in math class in one or both of these contexts:
* **7.G.A.1** Solve problems involving scale drawings of geometric figures, including computing actual lengths and areas from a scale drawing and reproducing a scale drawing at a different scale.
* **7.RP.A.2** Recognize and represent proportional relationships between quantities.
* There are multiple connections between the work students will be doing in Lesson 7 and the work they will be doing in math class this year (grade 8). These include the following:
* **8.F.B.5** Describe qualitatively the functional relationship between two quantities by analyzing a graph (e.g., where the function is increasing or decreasing, linear or nonlinear).
* **8.EE.A.1** Know and apply the properties of integer exponents to generate equivalent numerical expressions.

In lesson 4, students are introduced to lines of best fit in Lesson 4 . They see an example of such a line again in the Lesson 10 assessment. Students do not have to have encountered this idea in previous mathematics instruction. Lesson 4 assumes that this may be the first time students encountered this idea.

### What additional strategies are available to support equitable science learning in this unit?

OpenSciEd units are designed to promote equitable access to high-quality science learning experiences for all students. Each unit includes strategies which are integrated throughout the OpenSciEd routines and are intended to increase relevance and provide access to science learning for all students. OpenSciEd units support these equity goals through several specific strategies such as (1) integrating Universal Design for Learning (UDL) Principles during the unit design process to reduce potential barriers and provide more-accessible ways in which students can engage in learning experiences; (2) developing and supporting classroom norms that provide a safe learning culture; (3) supporting classroom discourse to promote students in developing, sharing, and revising their ideas; and (4) specific strategies to supporting emerging multilingual students in science classrooms.

Many of these strategies are discussed in the *Teacher Guides* in sidebar callout boxes titled “Attending to Equity” and subheadings such as “Supporting Emerging Multilingual Learners” or “Supporting Universal Design for Learning.” Other callout boxes with strategies are found as “Additional Guidance”, “Alternate Activity,” and “Key Ideas” and various discussion callouts. Finally, each unit includes the development of a Word Wall as part of students’ routines to “earning” or “encountering” scientific language.

For more information about each of these different strategies with example artifacts, please see the *OpenSciEd Teacher Handbook*.

### What are recommended adult-level learning resources for the science concepts in this unit?

The OpenSciEd instructional model focuses on the teacher being a member of the classroom community, supporting students to figure out scientific ideas motivated by their questions about phenomena. Students iteratively build their understanding of phenomena as the unit unfolds. To match the incremental build of a full scientific explanation across the unit, the science content background necessary for you to teach individual lessons incrementally builds too. Throughout the unit, we provide just-in-time science content background for you that is specific to the Disciplinary Core Ideas (DCIs) that will be figured out in a lesson. Places to look for this guidance include the “Where we are going” and “Where we are not going” sections for each lesson. Additionally, the expected student responses, keys, and rubrics have illustrated important science ideas that should be developed in each lesson. In addition to this information, the K-12 Science Framework is a great resource to learn more about the DCIs in this unit ([PS2.A](https://www.nap.edu/read/13165/chapter/9); [PS3.A](https://www.nap.edu/read/13165/chapter/9); [PS3.C](https://www.nap.edu/read/13165/chapter/9); [PS3.C](https://www.nap.edu/read/13165/chapter/9); [ETS1.B](https://www.nap.edu/read/13165/chapter/12); [ETS1.C](https://www.nap.edu/read/13165/chapter/12)), including what students have learned previously and where they are headed in high school. In addition to the science content background information embedded in the lesson resources, below we provide recommended resources that can help build your understanding of phenomena and Performance Expectations bundle for this unit:

* To learn more about forces:
* Newton's Laws: Crash Course Physics #5- [https://www.youtube.com/watch?v=kKKM8Y-u7ds&list=PL8dPuuaLjXtN0ge7yDk\_UA0ldZJdhwkoV&index=6](https://www.youtube.com/watch?v%3DkKKM8Y-u7ds%26list%3DPL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV%26index%3D6)
* Friction: Crash Course Physics #6- [https://www.youtube.com/watch?v=fo\_pmp5rtzo&list=PL8dPuuaLjXtN0ge7yDk\_UA0ldZJdhwkoV&index=7](https://www.youtube.com/watch?v%3Dfo_pmp5rtzo%26list%3DPL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV%26index%3D7)
* Collisions: Crash Course Physics #10- [https://www.youtube.com/watch?v=Y-QOfc2XqOk&list=PL8dPuuaLjXtN0ge7yDk\_UA0ldZJdhwkoV&index=11](https://www.youtube.com/watch?v%3DY-QOfc2XqOk%26list%3DPL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV%26index%3D11)
* To learn more about position and kinematic equations:
* Motion in a Straight Line: Crash Course Physics #1- [https://www.youtube.com/watch?v=ZM8ECpBuQYE&list=PL8dPuuaLjXtN0ge7yDk\_UA0ldZJdhwkoV&index=2](https://www.youtube.com/watch?v%3DZM8ECpBuQYE%26list%3DPL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV%26index%3D2)
* To learn more about vectors:
* Vectors and 2D Motion: Crash Course Physics #4- [https://www.youtube.com/watch?v=w3BhzYI6zXU&list=PL8dPuuaLjXtN0ge7yDk\_UA0ldZJdhwkoV&index=5](https://www.youtube.com/watch?v%3Dw3BhzYI6zXU%26list%3DPL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV%26index%3D5)
* To learn more about energy transfers between systems at the middle school level:
* Modeling energy transfers between systems to support energy knowledge in use- <https://www.tandfonline.com/doi/full/10.1080/03057267.2018.1598048>
* Conservation of Energy and Energy Transfer- <https://thewonderofscience.com/videos/2017/12/10/ps3b-conservation-of-energy-and-energy-transfer>

# Guidance for Developing Your Word Wall

This unit refers to two categories of academic language (i.e., vocabulary). Most often in this unit, students will have experiences with and discussions about science ideas before they know the specific vocabulary word that names that idea. After students have developed a deep understanding of a science idea through these experiences, and sometimes because they are looking for a more efficient way to express that idea, they have “earned” that word and can add the specific term to the class Word Wall. These “words we earn” should be recorded on the Word Wall using the students’ own definition whenever possible. On the other hand, “words we encounter” are “given” to students in the course of a reading, video, or other activity, often with a definition clearly stated in the text. Sometimes, words we encounter are helpful just in that lesson and need not be recorded on the Word Wall. However, if a word we encounter will be frequently referred to throughout the unit, it should be added to the Word Wall. As such, the Word Wall becomes an ongoing collection of words we will continue to use, including all the words we earn in the unit and possibly a few key words we encounter.

It is best for students if you create cards for the Word Wall in the moment, using definitions and pictorial representations that the class develops together as they discuss their experiences in the lesson. When they co-create the posted meaning of the word, students “own” the word—it honors their use of language and connects their specific experiences to the vocabulary of science beyond their classroom. It is especially important for emergent multilingual students to have a reference for this important vocabulary, which includes an accessible definition and visual support.

Sometimes creating Word Wall cards in the moment is a challenge. The teacher guide provides a suggested definition for each term to support you in helping your class develop a student-friendly definition that is also scientifically accurate. If you keep one Word Wall in your classroom for several sections of students, you might choose to record each class’s definition separately, and then propose an “official” definition to post the next day that captures the collected meaning.

The words we earn and words we encounter in this unit are listed in this document and in each lesson to help prepare and to avoid introducing a word before students have earned it. They are not intended as a vocabulary list for students to study before a lesson, as that would undermine the authentic and lasting connection students can make with these words when they are allowed to experience them first as ideas they’re trying to figure out.

| **Lesson** | **Words we earn** | **Words we encounter** | **Words from previous unit** |
| --- | --- | --- | --- |
| 1 | collision |  |  |
| 2 | force, kinetic energy, damage |  |  |
| 3 | contact force, deform |  |  |
| 4 | line of best fit, elastic limit, breaking point |  | Independent variable, dependent variable |
| 5 | peak force, free body diagram |  |  |
| 6 |  | concussion, axon |  |
| 7 |  |  |  |
| 8 | stored (potential) energy | air resistance, friction |  |
| 9 | air resistance, friction |  |  |
| 10 |  |  |  |
| 11 |  |  | criteria, constraints, stakeholders |
| 12 |  |  |  |
| 13 |  |  |  |
| 14 |  |  | trade-off |
| 15 |  |  |  |

# ASSESSMENT SYSTEM OVERVIEW

Each OpenSciEd unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self-assessment. The table below outlines where key assessments can be found in the unit. Key formative assessments are identified here, but many more opportunities are embedded in each lesson, and guidance for those also appears in the following table.

Each OpenSciEd unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self assessment. Formative assessments are embedded and called out directly in the lesson plans. Please look for the “Assessment Icon” in the teacher support boxes to identify places for assessments. In addition, the table below outlines where each type of assessment can be found in the unit.

## Overall Unit Assessment

| When | Assessment and Scoring Guidance | Purpose of Assessment |
| --- | --- | --- |
| Lesson 1 | Initial Model: Objects During Collisions | **Pre-Assessment**  Lesson 1 is an opportunity to uncover students’ initial ideas and questions about how damage sometimes happens to objects in collisions. Analyzing student work will allow you to see if students have skills from prior grade bands (what a force is, balanced and unbalanced forces, energy is transferred in collisions, energy can be transferred through forces, and so forth) and if they have some current grade-band understandings (mass and speed as factors related to kinetic energy; net force ideas; and so forth).  Use students’ initial models of collisions and the Consensus Discussion as a pre-assessment opportunity. In the Consensus Discussion, it is best if you select students who will share a wide variety of ideas. Disagreement among students about what causes damage to objects in a collision will motivate students to find answers throughout the unit. Disagreement will also help students develop a Driving Question Board with questions they will answer throughout the unit. |
| Lesson 4 | Independent, Dependent, and Controlled Variables | **Formative**  At the start of Lesson 4, students express their initial ideas about important variables in an investigation. The handout *Independent, Dependent, and Controlled Variables* can be used as a reference for students throughout the unit and throughout 8th grade as they continue to design and carry out investigations. |
| Lesson 5 | Slide K and related science notebook entry | **Formative**  This is a good opportunity to determine if students can plan investigations in small groups without a lot of scaffolding. Slide K cues students to start planning their investigation with their group. You can assess much of this plan before groups go to carry out the investigation and collect the data from it. Look for   * identification of a single independent variable * identification of the dependent variables * identification of important variables to keep constant * a data table with results from at least two conditions tested * peak forces measurements and/or equalities or inequalities noted for both push-pull spring scales for each condition tested * results from repeated trials for each condition (optional) * source(s) of error in the system (optional) |
| Lesson 6 | Soccer Assessment  Soccer Assessment Key | **Formative**  This is a putting-the-pieces-together lesson. It includes an assessment that provides students an opportunity to apply their understanding of peak forces, damage, and kinetic energy on different parts of a system in a collision. Students also draw free-body diagrams of the parts of a system during a collision. It’s critical that students first understand that the forces during a collision are always equal and opposite and that the peak forces experienced by each object are the same before they attempt to make a free-body diagram describing that relationship. However, once students become adept at using the free-body diagram to describe forces and energy transfer as objects interact, they will better be able to use free-body diagrams to predict the changes in motion to objects and changes in kinetic energy in a collision. |
| Lesson 10 | Lesson 10 Assessment  Lesson 10 Assessment Key | **Summative and Formative**  This is a putting-the-pieces-together lesson. It includes a summative midpoint assessment that can provide formative information for moving forward in the unit. The goal of the assessment is to determine if students can apply their evidence from lab activities and key science ideas to explain how objects sometimes break when they hit each other.  This lesson is also an excellent opportunity to revisit the Driving Question Board to identify questions that can be answered so far. The lesson includes guidance for supporting students in selecting their own questions they feel they can now answer and sharing those answers with the class.  This lesson assessment also provides an additional opportunity to re-assess students over ideas presented in Lesson Set 1. |
| Lesson 11 | Protection Device Design Thinking  Drafting Our Protection Device Design | **Pre-assessment**  This lesson provides an opportunity to find out what students may already understand the relationship between material properties and their abilities to reduce peak forces in a collision. Students will draw a diagram of their own protective device designs for an object of their choice and will try to describe these protective materials from a microscopic and macroscopic level, giving an idea of student understanding of scale, system models, and structure and function of the materials. Students will develop their understanding of how material properties reduce peak forces on the objects they are protecting in Lessons 12-14. |
| Lesson 14 | Lesson 14 Device Redesign | **Summative**  This is a putting-the-pieces-together lesson. It includes a summative assessment that gives students the opportunity to explore various types of padding and explain how padding helps ensure that objects in collisions change motion using small forces over long distances (rather than large forces over short distances). Then students apply their understanding from the entire unit to their own design idea. These material properties are used to refine designs, and trade-offs of different material choices are examined. Students have to apply the ideas of structure and function while considering stakeholder feedback and trade-offs to optimize their designs (ETS1). |
| Lesson 15 | Part 1: Cheerleading Headgear Assessment  Part 2: Cheerleading Headgear Assessment  Part 1 Key: Cheerleading Headgear Assessment  Part 2 Key: Cheerleading Headgear Assessment  Item alignment guide | **Summative**  This lesson provides an end-of-unit assessment to assess student understanding of peak forces, material structure, net force, and equal and opposite forces relationships. Students apply this knowledge to evaluate cheerleading helmets for safety, support or refute claims about the protective qualities of the device, explain the structural properties of protective materials and how they can contribute to a reduction of peak forces on the object they are protecting, and design a new device while considering the needs of stakeholders.  This end-of-unit assessment provides evidence of student understanding in the concepts above and an additional opportunity to assess key ideas from Lesson Sets 1 and 2. See the alignment guide for further details about the alignment of questions to the science and engineering practices. crosscutting concepts, and disciplinary core ideas for the unit. |
| After each lesson | Lesson Performance Expectation Assessment Guidance | **Formative Assessment**  Use this document to see which parts of lessons or student activity sheets can be used as embedded formative assessments. |
| Occurs in most lessons | Progress Tracker | **Formative and Student Self-Assessment**  The Progress Tracker is a thinking tool that was designed to help students keep track of important discoveries that the class makes while investigating phenomena and figure out how to prioritize and use those discoveries to develop a model to explain phenomena. It is important that what the students write in the Progress Tracker reflects their own thinking at that particular moment in time. In this way, the Progress Tracker can be used to formatively assess individual student progress or for students to assess their own understanding throughout the unit. Because the Progress Tracker is meant to be a thinking tool for students, we strongly suggest it is not collected for a summative “grade” other than for completion. |
| Anytime after a discussion | Student Self-Assessment Discussion Rubric | **Student Self-Assessment**  The student self-assessment discussion rubric can be used anytime after a discussion to help students reflect on their participation in the class that day. Choose to use this at least once a week or once every other week. Initially, you might give students ideas for what they can try next time to improve, such as sentence starters for discussions. As students gain practice and proficiency with discussions, ask for their ideas about how the classroom and small-group discussions can be more productive. |
| After students complete substantial, meaningful work | Peer Feedback Facilitation: A Guide | **Peer Feedback**  There will be times in your classroom when facilitating students to give each other feedback will be very valuable for their three-dimensional learning and for learning to give and receive feedback from others. We suggest that peer review happens at least two times per unt. This document is designed to give you options for how to support this in your classroom. It also includes student-facing materials to support giving and receiving feedback along with self-assessment rubrics where students can reflect on their experience with the process.  Peer feedback is most useful when there are complex and diverse ideas visible in student work, and not all work is the same. Student models or explanations are good times to use a peer feedback protocol. They do not need to be final pieces of student work, rather, peer feedback will be more valuable to students if they have time to revise after receiving the peer feedback. It should be a formative, not summative, type of assessment. It is also necessary for students to have experience with past investigations, observations, and activities where they can use these experiences as evidence for their feedback. |

For more information about the OpenSciEd approach to assessment and general program rubrics, visit the OpenSciEd Teacher Handbook.

## Lesson-by-Lesson Assessment Opportunities

Every OpenSciEd lesson includes one or more lesson-level performance expectations (LLPEs). The structure of every LLPE is designed to be a three-dimensional learning, combining elements of science and engineering practices, disciplinary core ideas and cross cutting concepts. The font used in the LLPE indicates the source/alignment of each piece of the text used in the statement as it relates to the NGSS dimensions: alignment to Science and Engineering Practice(s), alignment to Cross-Cutting Concept(s), and alignment to the Disciplinary Core Ideas.

The table below summarizes opportunities in each lesson for assessing every lesson-level performance expectation (LLPE). Examples of these opportunities include student handouts, home learning assignments, progress trackers, or student discussions. Most LLPEs are recommended as potential formative assessments. Assessing every LLPE listed can be logistically difficult. Strategically picking which LLPEs to assess and how to provide timely and informative feedback to students on their progress toward meeting these is left to the teacher's discretion.

| Lesson | Lesson-Level Performance Expectation(s) | Assessment Guidance |
| --- | --- | --- |
| Lesson 1 | **1.A** Develop a model to describe interactions between two objects as they collide and show the changes that occur in the structure of both objects when one object is damaged as a result and also when neither object is damaged as a result.  **1.B** Ask questions that arise from observations of collisions between two objects in order to seek additional information about factors (causes) that might affect the outcome of such collisions. | **1.A Developing and Using Models; Stability and Change; Systems and System Models**  **When to check for understanding:** Collect students’ initial models on *Initial Model: Objects During Collisions* and explanations on *Object Interactions During A Collision* at the end of day 1 to pre-assess their fluency in developing a model.  **What to look for/listen for:** Prompts in this task ask students to engage in two elements of the modeling practice related to representing descriptive aspects of the phenomenon as well as unobservable mechanisms. These will provide an opportunity for students to use related DCIs from prior grades; grade 4 (energy transfer in collisions) and grade 2 (objects push each other when they collide). There are phrases in the prompts that ask students to consider related elements of CCCs, particularly systems and system models and stability and change. You may also see some students developing particle-level representations for changes happening in the matter in the system, based on their extensive work in developing such models in prior OpenSciEd units. See the related *Assessment* callout box for additional guidance.  **1.B Asking Questions and Defining Problems; Cause and Effect**  **When to check for understanding:** Since students will put their initials on the backs of these sticky notes, you will have a few opportunities to take stock of the kinds of questions students ask in this initial lesson after they are posted on the DQB as well as when they first write them. When students share these questions for the DQB, they will likely have time to share only one. Collect the remaining questions that don’t get posted after the development of the DQB is complete. This record of questions they form today will help you formatively assess their fluency in the practice of asking questions at the start of this year. Collect and look through student notebooks to see their individual ideas for future investigations to pursue as well.  **What to look for/listen for:** See the related *Assessment* callout box for additional guidance. |
| Lesson 2 | **2.A** Collect data on changes in the motion and shape of colliding objects that serve as the basis for evidence that energy transfer occurs during the collision and that there are forces between colliding objects.  **2.B** Construct an argument supported by empirical evidence and scientific reasoning to support a model showing that changes in motion of colliding objects (connected to subsystems) results from energy transfer between them (cause) and changes in the shape of those objects results from force(s) between them (cause). | **2.A Planning and Carrying Out Investigations; Stability and Change**  **When to check for understanding:** Students carry out two investigations to explore what happens in collisions on day 1 of the lesson. In the first, the *Dropping and Breaking Lab*, they explore what happens to objects during a collision by dropping rigid objects on other objects. Students encounter challenges in understanding what’s happening at the moment of contact in collisions and help identify a plan for the *Exploring Horizontal Collisions Lab* to improve their ability to make observations.  **What to look/listen for:** Listen for students to suggest ways to control the collisions they observe. For example, students will likely suggest the use of slow-motion video or zoomed-in images of the moment of collision. They are likely to suggest that they want to see how the materials themselves are changing during the time the objects are in contact with each other. They may also suggest ways to control the motion and speed of objects in collisions, such as a way to target or line up the objects to ensure that they will collide after one or both are put into motion.  **2.B Engaging in Argument from Evidence; Stability and Change; Cause and Effect; System and System Models**  **When to check for understanding**   1. Students develop cause-and-effect statements to account for mechanisms responsible for the changes in motion and shape during collisions in day 2 of the lesson. 2. Students also update their Progress Trackers at the end of day 2 with what they figure out related to their lesson question. This provides a second opportunity to formatively assess student understanding.   **What to look/listen for**   1. Students making arguments that leverage prior knowledge about changes in kinetic energy, energy transfer, and/or forces in the initial cause-and-effect statements they make 2. Students making claims that refer to how energy transfer can help account for changes in motion and for how forces can account for changes in shape (students may also mention that forces can account for changes in motion as well) |
| Lesson 3 | **3.A** Construct and revise a written argument using evidence from various sources of data (slow-motion videos, photos, and firsthand investigations) to support or refute the claim that all objects do bend or change shape when pushed in a collision. | **3.A Engaging in argument from evidence; stability and change**  **When to check for understanding:** Check for student progress in their responses they write for their initial claim on in their notebooks.  **What to look/listen for:** Students should identify that the evidence supports the claim that all objects bend or change shape when pushed in a collision. |
| Lesson 4 | **4.A** Plan an investigation, identifying controls to keep constant, and carry out the investigation to produce data to serve as the basis for evidence to develop a mathematical model for the relationship (pattern) between the amount of force applied to an object and the amount it deforms.  **4.B** Analyze and interpret graphical data (patterns) from tests of compression force vs. amount and type of deformation (temporary vs. permanent) to provide evidence that supports an argument that all objects behave elastically up to a specific limit beyond which permanent damage occurs (stability and change). | **4.A Planning and Carrying out Investigations; Patterns, Cause & Effect, Stability & Change**  **When to check for understanding:** Completion of *Independent, Dependent, and Controlled Variables* will provide a useful reference text for future investigations that students will plan in small groups in later lessons and future OpenSciEd units in 8th grade.  **What to look/listen for:** Look for students to do the following in the planning of the investigation:   * identify the independent variable as the amount of force applied to an object, * identify the dependent variable as the amount of deformation in the object, and * identify controls including where the force is applied and how much of the object overlaps the two supports (bricks) in each test.   **4.B Analyzing and Interpreting Data; Patterns, Cause & Effect**  **When to check for understanding**  Students construct graphical displays of data from compression force vs. deformation tests to help identify a linear relationship that describes the elastic behavior of all objects in graphs they make at the end of day 1 on *Deformation Results*  **What to look/listen for**   * the *x*-axis labeled as the force applied to the object (in N) * the *y*-axis labeled as the amount of deformation in the object (in cm) * stretching out the intervals to maximize the use of the graph paper while still capturing the highest *x* value and highest *y* value * equal intervals identified on each axis * a straight line of best fit through the data that are represented with points drawn as open circles (anywhere the beam returned to its original shape after the weight was removed) |
| Lesson 5 | **5.A** Plan and carry out an investigation and identify patterns in the data collected from the investigation to provide evidence that when peak contact forces on each object during the collision are equal in strength, the strength of those forces increases when the mass or the speed of the object that was moving before the collision increases.  **5.B** Develop and use subsystem models (free body diagrams) to represent how the peak contact forces on two different objects compare in a collision and how these are related to corresponding changes in the kinetic energy of a moving object before it collides due to an change in its mass or the speed. | **5.A Plan and Carry out Investigations; Patterns, Systems and System Models**  **When to check for understanding: Slide K** cues students to start planning their investigation with their group. You can assess much of this plan before groups go to carry out the investigation and collect the data from it.  **What to look/listen for**   1. **Identification of a single independent variable:** mass or speed 2. **Identification of the following dependent variables:** the peak force measured on the push-pull spring scale on cart subsystem A and the peak force measured on the push-pull spring scale on cart subsystem B 3. **Identification of important variables to keep constant:** If students identified mass as the independent variable then they should identify speed as an important variable to try to keep constant. If students identified speed as the independent variable then they should identify mass as an important variable to try to keep constant. 4. **A data table** with results from at least two conditions tested (e.g., no additional mass vs. added mass or slower speed vs. faster) 5. **Peak forces measurements** and/or equalities or inequalities noted for both push-pull spring scales for each condition tested 6. **Results from repeated trials for each condition** (optional) 7. **Source(s) of error in the system** (optional)   **5.B Develop and Use Models; Systems and Systems Models**  **When to check for understanding:** Collect student exit tickets at the end of day 2 of this lesson.  **What to look/listen for:** Transferring the representations of the ideas developed in the class consensus model to a new context to explain a different phenomenon. The following ideas should be show up in students’ responses:   * A: Students identify one or both objects. * B: The forces would be equal in strength. * C: The kinetic energy would be less. * D: The forces would be weaker but still equal in strength. |
| Lesson 6 | **6.A** Apply science ideas and use evidence to construct an explanation for how the amounts of peak force and energy transfer (cause) in soccer collisions result in instability in the brain (concussions, effect) due to sudden changes at the cellular level. | **6.A Constructing Explanations and Designing Solutions; Cause and Effect; Stability and Change**  **When it happens:** Students use science ideas from Lessons 1-5 in *Soccer Assessment* to determine how peak forces and energy transfer affect different soccer collision scenarios.  **What to look/listen for**   * Peak forces on the head and the ball are shown as the same during a header, both drawn in the diagram in question 1 and the selected answer in question 2a. * Contact forces are applied to both objects and are always equal regardless of speed or mass in question 2b. * Identification of case c in questions 3a and 3b as having the least amount of total kinetic energy in they system before the collision. * Collisions with objects that are moving with a greater mass or speed in comparison with collisions that have lesser mass and speed will experience more peak force, as seen in the two potential answers for question 5. * See *Soccer Assessment Key* for a more detailed analysis of what to look for in each question. |
| Lesson 7 | **7.A** Construct, analyze, and interpret graphical displays of data collected from a computer simulation to identify patterns in the data, including a linear relationship between the mass of a moving object and its kinetic energy and its kinetic energy and a nonlinear relationship between the speed of a moving object and its kinetic energy.  **7.B** Construct an explanation based on quantitative relationships (scale) for whether decreasing the mass of a moving object or decreasing its speed would have a bigger effect on the peak forces produced in a collision between it and a stationary object and use these ideas to further explain why this would cause damage in some collisions but not others (effect). | **7.A Analyze and Interpret Data; Patterns**  **When to check for understanding:** On day 2 of the lesson when students construct two graphs of their data from the computer simulation on copies of *Graphing Kinetic Energy Relationships* and when they discuss the patterns they notice in these with a partner, per slide K, and then share these patterns with the whole class  **What to look for/listen for:** See the assessment callout box for guidance on what to look for in students’ graphs and student discussions.  **7.B Constructing explanations and designing solutions; scale, cause and effect**  **When to check for understanding:** At the end of day 2 of the lesson when students individually complete questions 3-5 on *Looking back: Explaining and predicting kinetic energy changes in the system*  **What to look for/listen for:** Students should be setting up, labeling, and adding data appropriately to graphs. See the assessment callout box for specific guidance on what to look for in student responses. |
| Lesson 8 | **8.A** Develop and use a model to identify other parts of the system the cart and box are making contact with or colliding into that could be producing contact forces on these subsystems, causing energy to be transferred to or from them as the box and cart travel down the track. | **8.A Develop and use a model, systems and system models, energy and matter.**  **When it happens:** In the student responses you collect on *Modeling other force interactions in the launcher, cart, box, and track system* at the end of the lesson  **What to look for:** See *Key for modeling force interactions in the launcher, cart, box, and track system* for guidance on what to look for in student responses. |
| Lesson 9 | **9.A** Apply scientific ideas and evidence to construct an explanation for the causes of motion and kinetic energy changes that happen before and after collisions and how these affect the outcome of a collision.  **9.B** Respectfully provide and receive critiques about claims to identify relevant evidence to support an explanation for how energy transfers through the cart-launcher system before and right after a collision.  **9.C** Develop and revise a model to identify other parts of the system the cart and box are making contact with or colliding into that are producing contact forces on these subsystems, causing energy to be transferred to or from them as the box and cart travel down the track. | **9.A Planning and Carrying Out Investigations; Cause and Effect**  **When to check for understanding:** In day 1 of this lesson, students carry out investigations and examine data at four stations to build understanding of forces due to friction and air resistance and how these affect motion and kinetic energy (KE) of subsystems in the collision system model.  **What to look for:** Students should use the patterns they notice to develop cause-effect relationships between observable changes at the macroscopic scale and the particle nature of interactions at the microscopic scale. Students should attribute slowing down or losing energy to particle interactions due to air resistance and friction between surfaces that slide past each other.  **9.B Engaging in Argument from Evidence; Energy and Matter**  **When to check for understanding:** After students collect evidence and analyze data on day 1 of this lesson, they write claims about the cause-effect relationships between changes in motion and in kinetic energy and particle nature of interactions due to friction and air resistance. They will present and defend their claims on day 2 and engage in discussion to deepen their thinking.  **What to look for:** Listen for students to share similarities and differences in the evidence and reasoning they cite to support their claims. Students should be describing the relationship between the particle nature of air and the surfaces of objects sliding past each other.  **9.C Develop and use a model, systems and system models, energy and matter.**  **When it happens:** In the revised student responses on *Modeling other force interactions in the launcher, cart, box, and track system* you will collect at the start of the next lesson after redistributing the previously collected responses back to students at the end of this lesson  **What to look for:** See *Key for modeling force interactions in the launcher, cart, box, and track system* for guidance on what to look for in student responses you will collect at the start of Lesson 10. Compare the responses with those students provided at the end of Lesson 8. |
| Lesson 10 | **10.A** Apply scientific ideas to explain why some collision-related phenomena resulted in damage while others did not and to explain how the contributing factors (energy, matter, peak forces) could change to result in different collision outcomes.  **10.B** Apply scientific ideas to explain multiple baseball phenomena, including the effects of air density and wind on ball speed (changes to the stability of the system and its effect on kinetic energy changes due to air resistance), bat mass vs. bat speed (interpreting patterns in graphical and tabular data to determine the linear and nonlinear effects on increases of kinetic energy within the system), and bat type (the effect deformation has on peak forces in the system and kinetic energy) on how the game is played. | **10.A Constructing Explanations and Designing Solutions; Cause and Effect; System and System Models**  **When it happens:** Students use *Explaining a Collision* to explain why a collision type resulted in damage or no damage during a collision and what factors (mass, speed, KE, friction, air resistance) could be altered to produce a different collision outcome.  **What to look/listen for:** Look for students to use the ideas off of the Big Ideas poster.  In box 1, look for these ideas:   * representing the kinetic energy of the moving object as greater than that of the nonmoving object * forces due to air resistance and friction acting on the moving object before the collision * force arrows that are representative of the relative amounts of force acting in the moving object and in the proper direction and whose arrow tip is touching the surface the force is acting on   In box 2 look for these ideas:   * objects bending or deforming (momentarily or permanently) * each object experiencing the same amount of peak force, but in opposite directions * energy being transferred in the system between the colliding objects at the moment of contact * Optional: If the objects are made of different materials, they could show different amounts of deformation for the same amount of force. Though students know this should be the case based on ideas they figured out in Lesson 4, because they won’t know the relative elasticity of each object in the system, they may not feel it’s valid to represent these relative differences in their models without having these specific data to inform which object would deform more or less than the other.   In box 3 look for these ideas:   * change in speed being represented as a larger factor than change in mass in reducing or increasing kinetic energy of the moving object(s) * greater or less air resistance and friction causing the increase or reduction of kinetic energy of the moving object(s) before the collision * changes listed above having an effect on the amount of deformation of each object at the moment of collision * changes in the amount of deformation of each object corresponding to whether or not it exceeds the elastic limit of the object to account for whether or not it is damaged   **10.B Constructing Explanations and Designing Solutions; Cause and Effect; System and System Models; Stability and Change**  **When it happens:** Students complete *Baseball Assessment 1* or the alternate version *Baseball Assessment 2* on day 2 of the lesson.  **What to look for**   * Questions 1-2: Students should show a decrease in ball speed attributed to the loss of energy due to air resistance. Students should justify this idea using free-body diagrams showing the relative strengths of air resistance due to wind speed. * Question 3: Students should use ideas for investigations that utilize experiences from previous labs in class. * Questions 4-6: Students will plot points based upon data, then predict a data point based on the line of best fit. * Question 7: Students should explain that an increase in bat mass would decrease swing speed due to the amount of energy needed to move a more-massive object. * Questions 8-9: Students should reflect an understanding that speed increases at a greater rate when kinetic energy is doubled. A decrease in air resistance would increase the visible effects of this relationship. * Question 10: Students should argue the warning on the bat supports the coach’s claim that it produces higher peak forces in a collision than other bats, but nothing on the warning provides information to support the claim that it deforms less in a collision. * Questions 11-12: These answers are subjective to viewpoint; see *Key 1: Baseball Assessment* and *Key 2: Baseball Assessment*. * See *Key 1: Baseball Assessment* and *Key 2: Baseball Assessment* for a more-detailed assessment guidance by question. |
| Lesson 11 | **11.A** Define a problem that can be solved with the development of a protective device to reduce damage (peak force) during a collision by identifying and considering multiple criteria and constraints along with specific materials, shapes, and designs of devices that reflect our science ideas of how certain material properties function in a collision.  **11.B** Design a solution to a problem to reduce the damage to an object in a collision (by reducing peak forces) by considering the properties of different, individual materials and shapes being used to serve particular functions. | **11.A Asking Questions and Defining Problems; Structure and Function**  **When it happens:** Students engage in defining a problem that could be solved with the design of a protective device for an object and identifying the overall purpose of a protective device in *Protection Device Design Thinking*. Students identify criteria and constraints and consider what materials and properties are important to the protective device.  **What to look for/listen for:** On *Protection Device Design Thinking* students define the purpose at the top of the page. Look for students to identify that the purpose of the device is for protection. Look for relevant criteria and constraints as students engage with the handout and for justification of the type of material and the shape of the materials they propose to use in their designs.  **11.B Constructing Explanations and Designing Solutions; Structure and Function**  **When it happens:** Students engage in designing a protective device for an object of their choosing when they complete *Drafting Our Protection Device Design*.  **What to look for/listen for:** Treat this as a pre-assessment of students’ understanding of new ideas that they will develop in the last lesson set of the unit. The first idea is related to the microscopic structure of cushioning materials. Many effective cushioning materials provide pockets or gaps of space or air between the layers of materials for the cushioner to “give”. Look for this in the second column of the design drawing. The second idea is related to how cushioners reduce peak forces in a collision. Look for these concepts:   * The amount of peak force is reduced because the cushioner applies a weaker force over a larger distance in a collision, which has as much effect on reducing the kinetic energy of an object as a stronger force over a shorter distance. * These forces are transferred to both objects that the cushioner is in contact with (including the object it is protecting). * The shape of a cushioner can be designed to distribute that force over a greater surface area, thereby reducing the amount of peak force occurring at a single location on the object being protected. |
| Lesson 12 | **12.A** Analyze data to determine which materials reduce peak force in a collision and analyze the similarities (visual patterns across materials) in the properties of those materials (macroscopic deformability).  **12.B** Develop a model to explain how the changes in the structures of cushioning materials contribute to their function (a reduction in peak forces) at a microscopic level during a collision. | **12.A Analyzing and Interpreting Data; Structure and Function, Patterns**  **When to check for understanding:** At the beginning of day 2, students individually reflect on data from the investigation to analyze the structure of multiple materials and look for patterns in structure. Students identify what structural patterns they see in the top performers and try to explain how these patterns in structure could better reduce peak force than other materials that did not perform as well.  **What to look for/listen for**  As students are individually reflecting on data, they should write about the patterns they see across multiple structures that were top performers. Students should identify that the better performers have space and/or air gaps in them and the ability to deform more than other materials that did not perform as well.  **12.B Developing and Using a Model; Structure and Function**  **When it happens:** *How can materials reduce peak force on the objects they protect?* provides an opportunity for formative assessment. Circulate as students are working on their explanations and collect the handout at the end of class.  **What to look for/listen for**   * Bubble wrap and cotton balls have a large amount of empty space or air in them and relatively small amounts of solid material across the space they take up. * Bubble wrap and cotton balls deform easily when a small force is applied. * Connecting structure to function, identifying a connection to reduction in peak force: e.g., less force between the cushioner and the object it is in contact with is due to increased space, ability to deform, less-solid material, more-flexible material, and so forth. * Possible student idea: Students may bring up particle-level connections, e.g., these materials are ones that would also exhibit less energy transfer through conduction (from prior units [unit:wc.n] and [unit:th.n]), which may be related to less peak force. |
| Lesson 13 | **13.A** Construct an explanation for how (and why) the structure of a cushioning material affects the peak forces produced (function) in a collision, relating the amount of space available for deformation, the total contact time during a collision, and the peak forces produced from the addition of such structures.  **13.B** Develop and use subsystem models (free body diagrams) to represent how the peak contact forces on different objects in a collision compare when they have different cushioning structures between them.  **13.C** Critically read a scientific text adapted for classroom use to determine how concussions can result in breaks in the axons of neurons (structure) and why this can lead to memory loss (function), how a snug fit (structure) for a helmet would affect its performance (function), and how other changes in the structure of cushioning material (in a helmet) would affect its performance (function). | **13.A Constructing Explanations and Designing Solutions, Developing and using models; patterns, structure and function**  **When it happens:** When students enter an individual Progress Tracker entry at the end of the first day of the lesson  **What to look for:**   * Good cushioning (force reduction) materials have space available in them for deformation. * More space available for deformation is related to an increased contact time during the collision. * Increased contact time in the collision is related to decreased peak forces produced in the collision. * Optional: Students may argue that thicker cushioning materials with spaces or air gaps in them available for deforming should therefore reduce peak forces more in a collision   **13.B Developing and using models; structure and function, stability and change**  **When it happens:** Slide H cues students to complete *Free body diagrams for collisions with and without cushioning structures* on their own after working on other parts of it with a partner.  **What to look for:** Look for the system diagram and free body diagrams shown in the related assessment support box.  **13.C. Obtaining, evaluating, and communicating information; structure and function**  **When it happens:** *Reading: Anatomy of a Bike Helmet* is distributed as a home learning assignment to be completed before the start of Lesson 14. Collect this completed assignment at the start of Lesson 14.  **What to look for:** Use of structure and function relationships in the responses to the questions on *Reading: Anatomy of a Bike Helmet*. See the related assessment guidance support box for more question-specific guidance. |
| Lesson 14 | **14.A** Optimize the performance of a design by prioritizing the particular functions and properties of materials based upon stakeholder feedback to assess the relative effectiveness of the materials.  **14. B** Engage in a quantitative analysis using prioritized scores and consider the trade-offs of prioritizing particular uses and functions of materials to assess their relative effectiveness for the optimization of the design. | **14.A Constructing explanations and designing solutions; Structure and function**  **When to check for understanding:** On day 2, students use *Additional Material Considerations Matrix* to assign rankings to their chosen considerations as primary, secondary, or tertiary considerations.  **What to look/listen for:** Look for students to appropriately assign primary, secondary, and tertiary criteria based on stakeholder feedback from *Decision Matrix*.  **14.B Constructing explanations and designing solutions; Structure and function**  **When to check for understanding:** On day 2, students will complete a three-column table in their notebooks considering the consequences of their design trade-offs and prioritization of considerations.  **What to look/listen for:** Look for students to list the design decisions they have made according to their redesign table and decision matrix. Students should explain the potential effects (which can be positive or negative) that each design decision will specifically have on stakeholder concerns or considerations. In column 3 students will consider what effect the decision will have on the overall design of the device and explain how those decisions impact the performance of the design (which can be positive or negative). |
| Lesson 15 | **15.A** Develop and use a series of models to represent (a) the relative strength of the forces (change and stability) being applied to three different objects and subsystems in contact in a collision, (b) in each case what interaction (cause) is producing this force (effect) on the object, and (c) the direction of these forces in three different free body diagrams and use the ideas from these models to support or refute an argument for the effect on peak forces on heads during a collision.  **15.B** Construct an explanation for why a design solution will optimize performance, including the prioritized criteria, constraints brought from stakeholders, and trade-offs made when revising the design to meet criteria.  **15.C** Design a solution to a problem to reduce the damage to an object in a collision (by reducing peak forces) by considering the properties of different materials and shapes being used to serve particular functions. | **15.A Developing and Using a model; stability and change, cause and effect**  **When it happens:** At the the end of day 1, students start part 1 of the assessment on *Part 1: Cheerleading Headgear Assessment*, where some of the questions on it (see *Item alignment guide*) are aligned to this practice and these related crosscutting concepts.  **What to look/listen for:** See *Part 1 Key: Cheerleading Headgear Assessment* for scoring guidance and anticipated responses.  **15.B and 15.C Constructing explanations and designing solutions; structure and function, cause and effect; stability and change.**  **When it happens:** During day 2, students complete part 2 of the assessment on *Part 2: Cheerleading Headgear Assessment*, where some of the questions on it (see *Item alignment guide*) are aligned to this practice and these related crosscutting concepts.  **What to look/listen for:** See *Part 2 Key: Cheerleading Headgear Assessment* for scoring guidance and anticipated responses. |
| Lesson 16 | **16.A** Communicate and present information orally about the proposed performance of a protective device, explaining how specific structures and materials have been manipulated to reduce peak forces in a collision. | **16.A Obtain, evaluate, and communicate information; Structure and function**  **When it happens:** This investor pitch presentation provides an additional opportunity after *Part 1: Cheerleading Headgear Assessment* or *Part 2: Cheerleading Headgear Assessment* to assess skills regarding the understanding of structure and function of material properties to reduce peak forces in a collision. An informal version of this assessment can be conducted while students are completing *Outlining an Investor Pitch Presentation*, and a formal assessment can occur during the investor pitch presentation (live or prerecorded).  **What to look/listen for**   * Listen for students to demonstrate understanding of the unit key ideas that were not fully met at the end of Lesson 15. See *Item alignment guide* for specific key ideas. * Students should list trade-offs and the reasoning behind those trade-offs to optimize their design solution. * Listen for the rationale for decisions that led to the optimization of the design. * Listen for students to include a rationale for their material choice that involves the properties of their material that help reduce peak forces during a collision, such as the ability of materials to deform, space for air, and distribution of contact forces over a greater surface area. * See *Potential Accompanying Standards* for details on additional standards to assess, if wanted. |

# HOME COMMUNICATION

Dear Guardian,

Your child’s 8th grade science class is starting a unit called, *Why do things sometimes get damaged when they hit each other*? as part of the OpenSciEd middle school science curriculum. This unit develops science ideas around forces, motion, and energy, like when objects collide. Students will apply these science ideas in an engineering task to design a way to protect an object of their choice. But first, students start with an all too familiar experience, a phone falling to the ground.

It’s hard to describe that feeling after a phone falls and before it’s picked up to be inspected. But relief is common when we realize nothing is broken. On average, Americans continue to break 2 smartphone screens every second. Students start the unit wondering about and describing moments when objects become damaged or not damaged after a collision. Students then draw models and conduct investigations to think about how structures interact as part of a broader system. Those models help students to think about energy and its role in collisions.

Students apply these science ideas in a design challenge to protect an object of their choice. Students will test out their designs to collect and to analyze their own data. Together, they then refine their ideas. For example, students will critique each other’s design solutions, identify trade-offs, and evaluate competing designs to prevent damage from collisions.

**Helping your child make sense of their learning:**

* Encourage your child to expand and clarify their own thinking by asking for examples, saying more about their ideas, and repeating what they said back to them.
* Ask how they might have arrived at a particular conclusion.
* Ask your child to recall what other students have said in class, and what about their ideas did they agree or disagree with.
* Rephrase or paraphrase what your child says as a way to clarify their ideas.
* If your child has completed the Cup Design Unit in 7th grade, ask them what they recall, how energy can transfer and what is similar and different from their learning so far.

**Having conversations about science:**

* Encourage your child’s curiosity through talking about their own noticings and wonderings when running errands or on a walk.
* Provide your child space and time to think aloud with a drawing, objects, or their voice about different (maybe conflicting) ideas for processing. Sometimes processing ideas won’t lead to a clear “answer” or solution yet.
* Ask your child to reflect on prior OpenSciEd units (e.g. One Way Mirror unit, Cup Design unit, etc.) to see connections about different science ideas and what’s around them.

Estimado guardián:

La clase de ciencias de 8º grado de su hijo está iniciando una unidad llamada *¿Por qué a veces las cosas se dañan cuando se golpean entre sí*? como parte del plan de estudios de ciencias de la escuela intermedia de OpenSciEd. Esta unidad desarrolla ideas científicas sobre fuerzas, movimiento y energía, como cuando los objetos chocan. Los estudiantes aplicarán estas ideas científicas en una tarea de ingeniería para diseñar una forma de proteger un objeto de su elección. Pero primero, los estudiantes comienzan con una experiencia demasiado familiar, un teléfono que cae al suelo.

Es difícil describir esa sensación después de que se cae un teléfono y antes de que lo levanten para inspeccionarlo. Pero el alivio es común cuando nos damos cuenta de que nada está roto. En promedio, los estadounidenses continúan rompiendo 2 pantallas de teléfonos inteligentes cada segundo. Los estudiantes comienzan la unidad preguntándose y describiendo momentos en los que los objetos se dañan o no se dañan después de una colisión. Luego, los estudiantes dibujan modelos y realizan investigaciones para pensar en cómo interactúan las estructuras como parte de un sistema más amplio. Esos modelos ayudan a los estudiantes a pensar sobre la energía y su papel en las colisiones.

Los estudiantes aplican estas ideas científicas en un desafío de diseño para proteger un objeto de su elección. Los estudiantes probarán sus diseños para recopilar y analizar sus propios datos. Juntos, luego refinan sus ideas. Por ejemplo, los estudiantes criticarán las soluciones de diseño de los demás, identificarán las compensaciones y evaluarán los diseños de la competencia para evitar daños por colisiones.

**Ayudar a su hijo a dar sentido a su aprendizaje:**

* Anime a su hijo a ampliar y aclarar su propio pensamiento pidiéndole ejemplos, diciendo más sobre sus ideas y repitiendo lo que les dijo.
* Pregunte cómo podrían haber llegado a una conclusión particular.
* Pídale a su hijo que recuerde lo que otros estudiantes han dicho en clase y con qué ideas estuvieron de acuerdo o en desacuerdo.
* Reformule o parafrasee lo que dice su hijo como una forma de aclarar sus ideas.
* Si su hijo completó la Unidad de diseño de vasos en 7º grado, pregúntele qué recuerda, cómo se puede transferir la energía y qué es similar y diferente de lo que ha aprendido hasta ahora.

**Tener conversaciones sobre ciencia:**

* Fomente la curiosidad de su hijo al hablar sobre sus propias observaciones y preguntas cuando hace mandados o camina.
* Proporcione a su hijo espacio y tiempo para pensar en voz alta con un dibujo, objetos o su voz sobre ideas diferentes (quizás contradictorias) para procesar. A veces, el procesamiento de ideas aún no conduce a una "respuesta" o solución clara.
* Pídale a su hijo que reflexione sobre unidades anteriores de OpenSciEd (p. ej., Unidad de Espejo unidireccional, Unidad de Diseño de vasos, etc.) para ver conexiones entre diferentes ideas científicas y lo que las rodea.