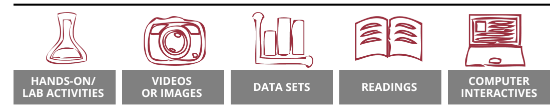
UNIT STORYLINE

Unit Question: Why do things sometimes get damaged when they hit each other?

How students will engage with each of the phenomena



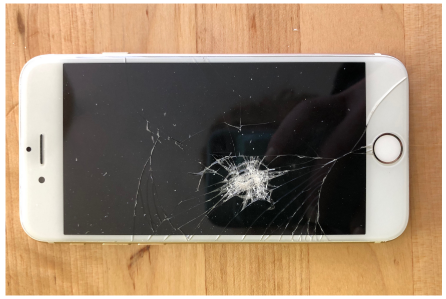
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it

LESSON 1

3 days

What happens when two things hit each other?

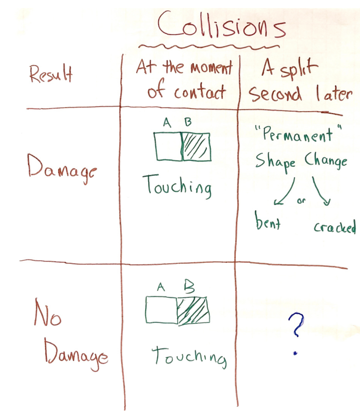
Anchoring Phenomenon



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.



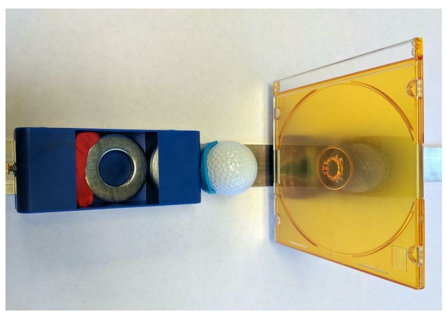
⇓ **Navigation to Next Lesson:** We have a lot of questions about what happens during a collision, so we are wondering if we can look more closely at what happens when different kinds of things collide.

LESSON 2

2 days

What causes changes in the motion and shape of colliding objects?

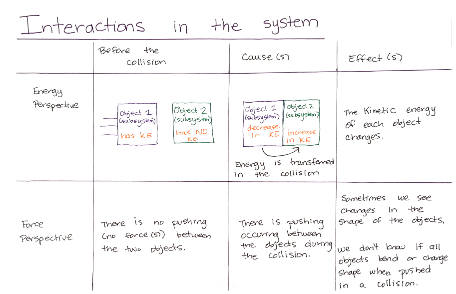
Investigation



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:

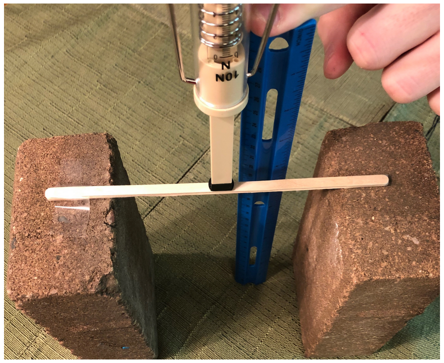
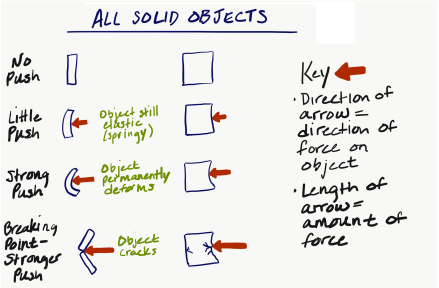
- A collision can cause the objects involved to change motion and/or change shape.
- Energy transfer occurs during a collision.
- There is a force(s) between objects when they make contact during a collision.



⇓ **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 Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 3 1 day **Do all objects change shape or bend when they are pushed in a collision?** Investigation	 *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 Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 4 2 days **How much do you have to push on any object to get it to deform (temporarily vs. permanently)?** Investigation	 *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.	

⇓ **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 Question	Phenomena or Design Problem	What we do and figure out	How we represent it

LESSON 5

2 days

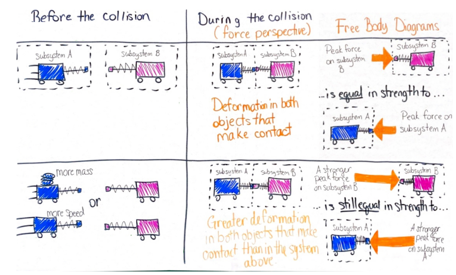
How does changing the mass or speed of a moving object before it collides with another object affect the forces on those objects during the collision?

Investigation

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.



⇓ **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

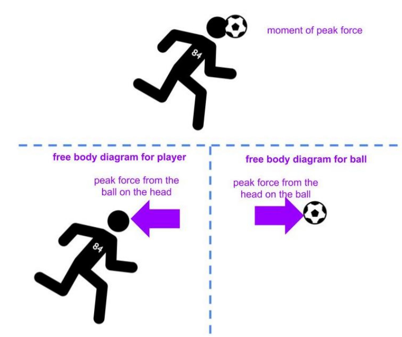
What have we figured out about objects interacting in collisions? How can we apply our new learning to answer questions about objects interacting in collisions?

Putting Pieces Together, Problematizing

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 what 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.



⇓ **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.

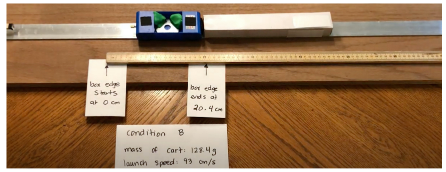
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it

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?

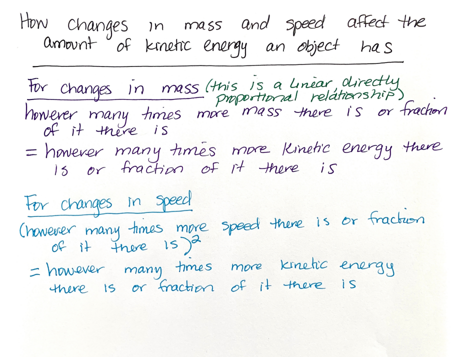
Investigation



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.



⇓ **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

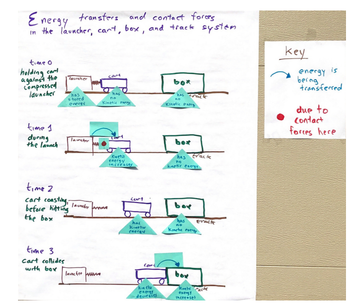
Where did the energy in our launcher system come from, and after the collisions where did it go to?

Investigation

A 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.



⇓ **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.

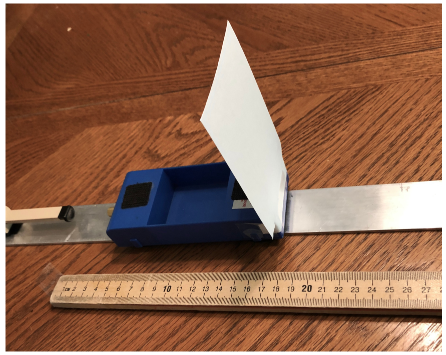
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it

LESSON 9

2 days

How do other contact forces from interactions with the air and the track cause energy transfers in the launcher system?

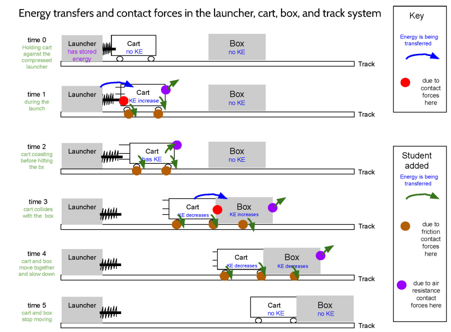
Investigation



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.



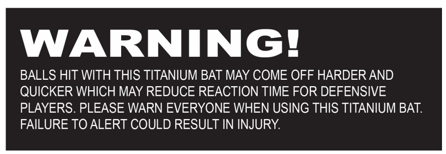
⇓ **Navigation to Next Lesson:** We know a lot about how damage occurs and we want to explain why some objects break and others don't in collisions.

LESSON 10

2 days

Why do some objects break or not break in a collision?

Putting Pieces Together



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

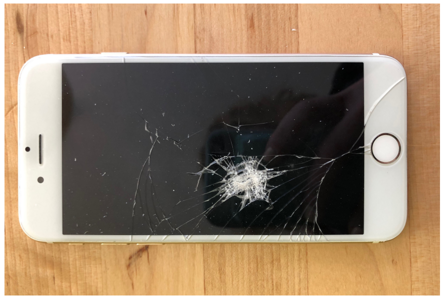
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it

LESSON 11

2 days

What can we design to better protect objects in a collision?

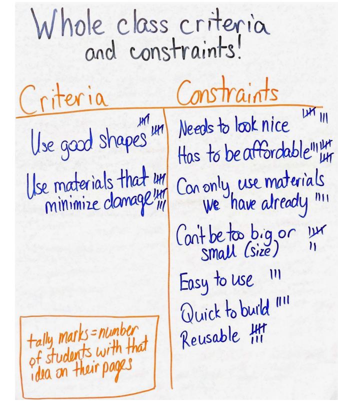
Anchoring Phenomenon



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.



⇓ **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

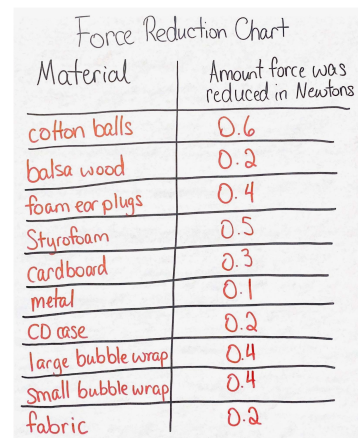
What materials best reduce the peak forces in a collision?

Investigation

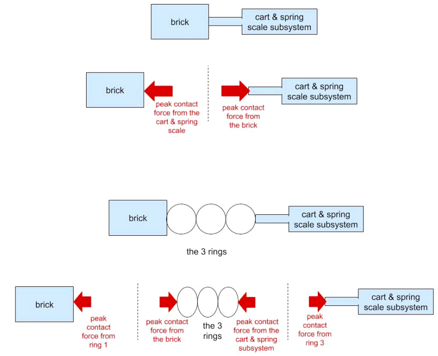
Materials that help to reduce peak force in a collision have similar structures, such as greater deformation abilities and air in their structures.

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:

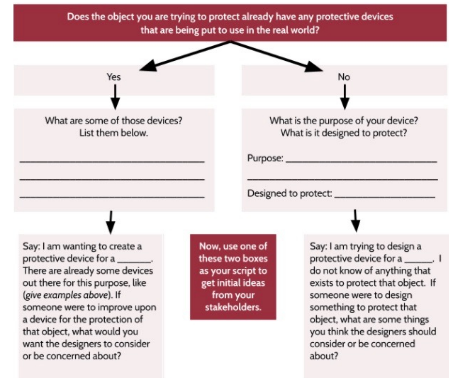
- Materials that reduce peak force have similar structures, such as air pockets or space for air, and the ability to deform when a contact force is applied; these materials reduce the peak force equally on both objects involved in the collision.



⇓ **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 Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 13 3 days **How (and why) does the structure of a cushioning material affect the peak forces produced in a collision?** Investigation	 *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.	

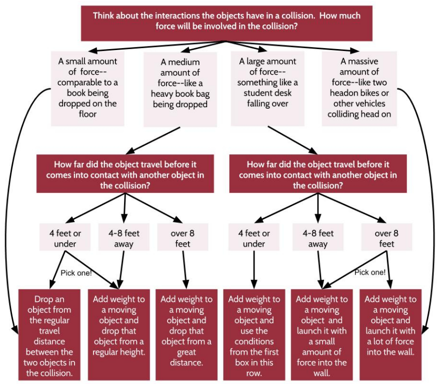
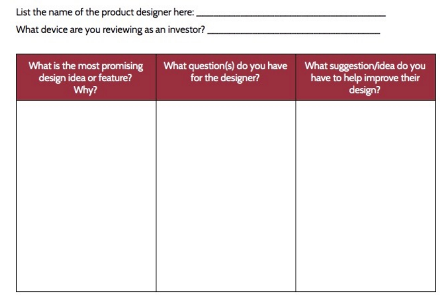
⇓ **Navigation to Next Lesson:** We started thinking about how what we have figured out could be applied to our protective device design solutions we have been working on as well as how they could be applied to another design problem we encountered earlier (protecting players' heads from concussion in a sports-related context). We are going to try to do this in the work we do across the next two lessons.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 14 2 days **How can we use our science ideas and other societal wants and needs to refine our designs?** Putting Pieces Together	 *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.	

⇓ **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 Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 15 2 days **How can we use what we figured out to evaluate another engineer's design?** Putting Pieces Together	 *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 Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 16 4 days **OPTIONAL How can we market our designs to our potential investors?** Putting Pieces Together	 *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.	 List the name of the product designer here: ______________________ What device are you reviewing as an investor? ______________________ What is the most promising design idea or feature? Why? | What question(s) do you have for the designer? | What suggestion/idea do you have to help improve their design?

⇓ **Navigation to Next Lesson:** There is no next lesson.

LESSONS 1-16

33 days total