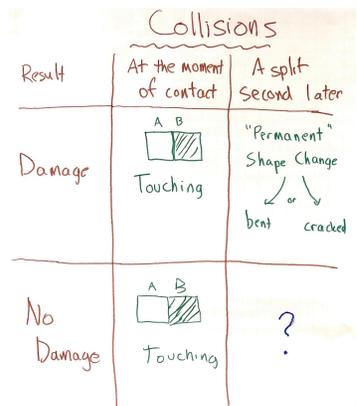


# UNIT STORYLINE

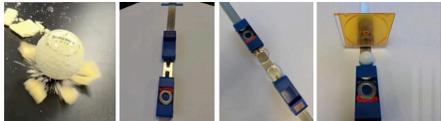
**Unit Question: Why does contact between objects sometimes cause damage, and how can we protect against it?**

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
<p><b>LESSON 1</b></p> <p>3 days</p> <p><b>What happens when two things hit each other?</b></p> <p>Anchoring Phenomenon</p> 	 <p>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.</p>	<p>We model what we think might happen at the moment of impact and a split second after 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:</p> <ul style="list-style-type: none"> <li>In a collision between two objects, the objects have to come into contact; sometimes something is damaged, but not always.</li> <li>Different factors and variables may cause objects to be damaged or not damaged in a collision.</li> </ul>	

↓ 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.

<p><b>LESSON 2</b></p> <p>2 days</p> <p><b>What causes changes in the motion and shape of colliding objects?</b></p> <p>Investigation</p> 	 <p>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.</p>	<p>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:</p> <ul style="list-style-type: none"> <li>A collision can cause the objects involved to change motion and/or change shape.</li> <li>Energy transfer occurs during a collision.</li> <li>There is a force(s) between objects when they make contact during a collision.</li> </ul>	
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↓ 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?**

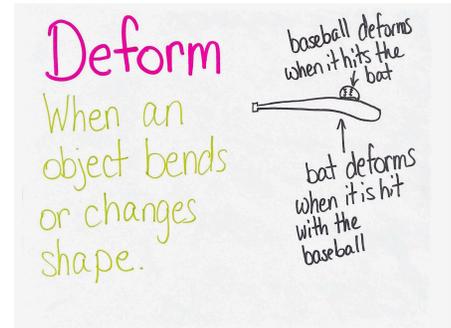
Investigation



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.



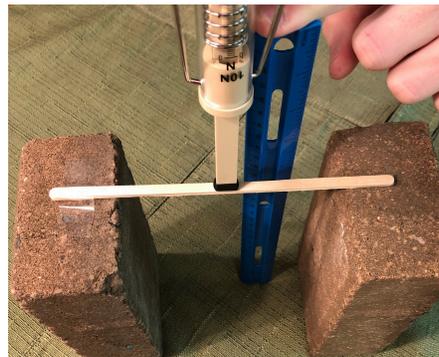
↓ **Navigation to Next Lesson:** Though we figured out that all solid objects deform, we are wondering how much force it takes to deform any solid object, and we started brainstorming ideas about how we could go about investigating this.

### LESSON 4

2 days

**How much do you have to push on any object to get it to deform (temporarily vs. permanently)?**

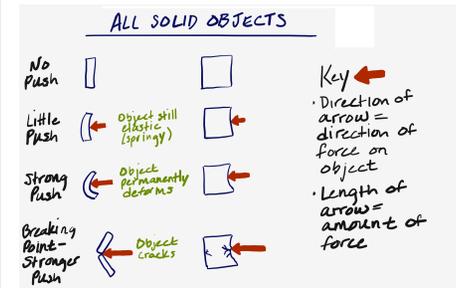
Investigation



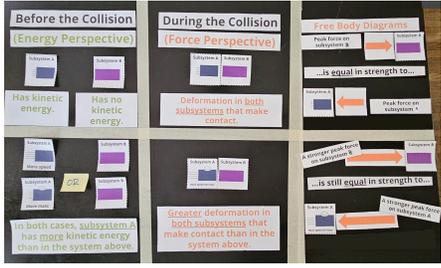
All materials have an elastic limit and will deform and return to their original shape in response to an applied force up to a point, beyond which permanent deformation occurs.

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 graph our data and compare these graphs to those from other materials tests. We develop a model to represent the elastic and non-elastic behavior of all solid objects in response to varying amounts of force applied to them. We figure out:

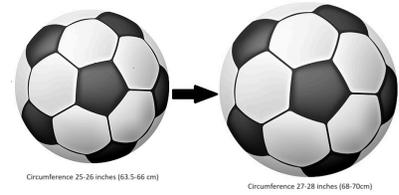
- All solid objects deform elastically when force is applied to them, up to a point.
- Different objects have a different elastic limit, which is the maximum amount of deformation they can withstand, beyond which they will deform permanently.
- Different objects have a different breaking point, which 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.



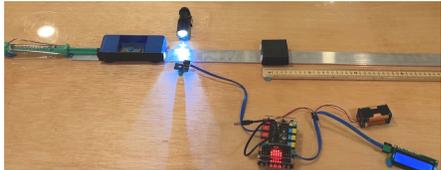
↓ **Navigation to Next Lesson:** Though we figured out that all solid objects elastically deform up to a point when forces are applied to them, we aren't really sure which objects are getting pushed on when one object is moving into a stationary object in a collision.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
<p><b>LESSON 5</b></p> <p>3 days</p> <p><b>How do the force interactions on the objects in contact compare?</b></p> <p>Investigation</p> 	  <p><i>When one of two objects (fingers or spring scales) are pushed against each other, both objects deform.</i></p>	<p>We carry out investigations and develop models to represent how the strength of those forces compare on objects in contact. We develop an input-changes-output model of a spring scale. We plan and carry out an investigation and develop a model to represent the relationship between differences in the kinetic energy of a moving object and the strength of the peak contact forces in a collision. We figure out:</p> <ul style="list-style-type: none"> <li>• When an object is motionless, any forces acting on it will be balanced--the ones acting in one direction will add up to those acting in the opposite direction (net force = 0N).</li> <li>• A spring scale is a device that changes an input to an output we can interpret as a measurement of the strength of a force.</li> <li>• A free body diagram represents the forces acting on a single object.</li> <li>• Objects that collide apply an equally strong peak contact force (maximum force) on each other in opposite directions during the collision, regardless of the mass or speed of those objects.</li> <li>• Increasing the speed or mass of a moving object increases its kinetic energy (KE).</li> </ul>	

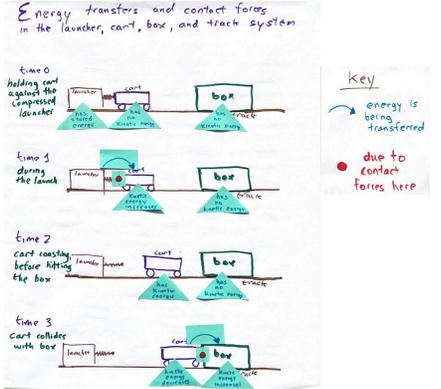
↓ **Navigation to Next Lesson:** We have a model that we think can be used to explain why some objects break and others don't in a collision. We want to test the use of this model on some of our initial questions and try to explain some new and related phenomena.

<p><b>LESSON 6</b></p> <p>1 day</p> <p><b>What have we figured out about objects interacting in collisions and how can we use those ideas?</b></p> <p>Putting Pieces Together, Problematising</p> 	 <p><i>Youth soccer players in the United States are experiencing more concussions. Acupressure mats can be used to support recovery from other, minor soccer injuries.</i></p>	<p>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:</p> <ul style="list-style-type: none"> <li>• We have made progress on many of our DQB questions.</li> <li>• We can apply our learning to answer questions about peak contact forces and damage caused by moving objects in soccer collisions, as well as questions about the forces in acupressure.</li> </ul>	 <p><small>Circumference 25-26 inches (63.5-66 cm)</small></p> <p><small>Circumference 27-28 inches (68-70cm)</small></p>
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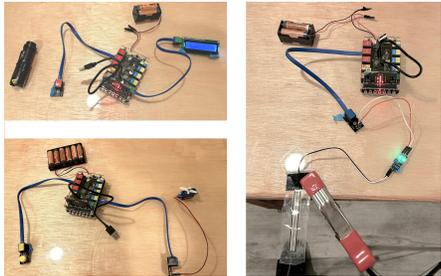
↓ **Navigation to Next Lesson:** During our discussion of assessment question 6, we discover we have conflicting ideas of what would cause more damage, increases in the mass or increases in speed of a moving object. We plan to investigate this further in our next lesson.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
<p><b>LESSON 7</b></p> <p>2 days</p> <p><b>How much does doubling the speed or doubling the mass affect the kinetic energy of an object?</b></p> <p>Investigation</p> 	 <p>A cart moving down a track collides with and sticks to a stationary cardboard box and moves the box a certain distance down the track before both the cart and box come to a stop.</p>	<p>We carry out two investigations using physical materials and a computational simulation to gather and analyze data. We use data to determine the effects of changing the mass or speed of an object on the kinetic energy of a second object in a collision. We figure out:</p> <ul style="list-style-type: none"> <li>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.</li> <li>The more kinetic energy an object has, the more you have to push against the direction of its motion to get it to stop.</li> <li>The more kinetic energy an object has, the more damage it can do in a collision.</li> </ul>	<p>How changes in mass and speed affect the amount of kinetic energy an object has</p> <p>For changes in mass (this is a linear directly proportional relationship)  however many times more mass there is or fraction of it there is  = however many times more kinetic energy there is or fraction of it there is</p> <p>For changes in speed  (whatever many times more speed there is or fraction of it there is)<sup>2</sup>  = however many times more kinetic energy there is or fraction of it there is</p>

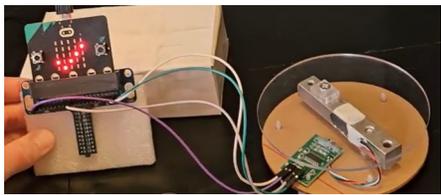
Navigation to Next Lesson: We have some initial ideas and some specific questions about where the energy is coming from and where it is going in our cart-launcher system.

<p><b>LESSON 8</b></p> <p>1 day</p> <p><b>Where did the energy in our launcher system come from, and after the collisions, where did it go?</b></p> <p>Putting Pieces Together</p> 	 <p>Different collisions have different effects on the cart and box system.</p>	<p>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 then revisit the Driving Question Board to evaluate our progress. We figure out:</p> <ul style="list-style-type: none"> <li>The more force you apply to an object, the more that object speeds up.</li> <li>It takes more force to speed up a more-massive object the same amount as a lower-mass object.</li> <li>Forces can cause a temporary (elastic) deformation of matter, which stores energy in the system. The amount of energy stored in the system is related to the amount of elastic deformation, as well as the thickness.</li> <li>The energy stored in all of these systems is sometimes referred to as potential energy.</li> <li>Contact forces transfer energy between different objects or subsystems within the larger cart-launcher system.</li> </ul>	
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Navigation to Next Lesson: We have answered a number of our questions but we still have some questions about force and how to measure it.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it																												
<p><b>LESSON 9</b></p> <p>2 days</p> <p><b>What inputs can different sensors detect and how can we repurpose them to respond to changes in the force applied to a system?</b></p> <p>Investigation</p> 	 <p><i>A micro:bit connected to a different type of sensor can respond to different types of input from the environment and produce different types of output (e.g., a display of letters, numbers, symbols, or making a sound).</i></p>	<p>We investigate five different sensors and record the changes we make (input) and the resulting data displays on the micro:bit (output). We discuss how these sensors are detecting forces or some other measurement that would let us measure a change in force. We work with a partner to brainstorm possible applications of the sensors. We figure out:</p> <ul style="list-style-type: none"> <li>Sensors can be used to detect different inputs such as changes in position, shape, or applied force and can result in different types of data output.</li> <li>The structures of sensors let us know how they function, and because of these structures, we can use sensors for a variety of applications.</li> </ul>	<p><u>Comparing Sensors</u></p> <table border="1"> <thead> <tr> <th>Sensor</th> <th>Input(s)</th> <th>Measures...</th> <th>Possible Uses</th> </tr> </thead> <tbody> <tr> <td>Accelerometer</td> <td>moved the box</td> <td>direction</td> <td></td> </tr> <tr> <td>Flex</td> <td>push or pull on sensor</td> <td>amount of bend</td> <td></td> </tr> <tr> <td>Rotary</td> <td>pushed on stick</td> <td>amount of movement or twist</td> <td></td> </tr> <tr> <td>Slide</td> <td>push or pull on knob</td> <td>location on knob/slide</td> <td></td> </tr> <tr> <td>Tilt</td> <td>moved the box</td> <td>direction</td> <td></td> </tr> <tr> <td>Light</td> <td></td> <td>change in light</td> <td>speedometer</td> </tr> </tbody> </table>	Sensor	Input(s)	Measures...	Possible Uses	Accelerometer	moved the box	direction		Flex	push or pull on sensor	amount of bend		Rotary	pushed on stick	amount of movement or twist		Slide	push or pull on knob	location on knob/slide		Tilt	moved the box	direction		Light		change in light	speedometer
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↓ Navigation to Next Lesson: We compared spring and digital scales found in the produce section of a local supermarket, which led us to wonder how digital scales measured forces.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it																											
<p><b>LESSON 10</b></p> <p>1 day</p> <p><b>How might a digital device measure forces more reliably than a spring scale?</b></p> <p>Investigation</p> 	 <p><i>Different types of digital scales contain similar structures, which have varying shapes that determine the amount of force the scale can detect.</i></p>	<p>We consider differences in how digital scales measure forces compared to spring scales. We watch a video of a digital scale dissection. We explore a digital load cell and identify the key structure that measures force. We look at images of the metal bar and record structures and their possible functions. We figure out that:</p> <ul style="list-style-type: none"> <li>Two different digital scales have similar structures in them: a) metal bar that serves a similar function as the spring in the spring scale, b) a small detector attached to the metal bar, c) batteries, d) a microchip/computer, e) a display/screen, and f) wires connecting these parts together.</li> <li>The ranges of force measurements that two different digital scales can provide are due to the differences in the elasticity and thickness of the metal bars in them.</li> </ul>	<table border="1"> <thead> <tr> <th>What are the parts (structures) of the digital scale?</th> <th>What do you think the structure does (function)?</th> <th>What are the parts (structures) of the digital load cell?</th> </tr> </thead> <tbody> <tr> <td>Metal top</td> <td>Place to apply force or put the stuff you weigh</td> <td>Clear plastic top</td> </tr> <tr> <td>Batteries</td> <td>Power source</td> <td>✓</td> </tr> <tr> <td>Buttons (mode/on/off/tare)</td> <td>Tell it what to do - units/ power/ zero?</td> <td>microbit buttons ??</td> </tr> <tr> <td>Metal bar with wires</td> <td>Measures weight - when something was put on it, the display output changed and wires send information Senses when a force is applied to it and wires send information</td> <td>✓ White glue with sensor underneath connected to the computer chip with wires</td> </tr> <tr> <td>Display screen</td> <td>Shows the weight</td> <td>microbit display ??</td> </tr> <tr> <td>Plastic housing</td> <td>Protects everything, holds everything in place</td> <td>Clear plastic bottom</td> </tr> <tr> <td>Wires</td> <td>Connect metal bar to computer chip, screen to batteries, computer chip to batteries Wires send signal between the metal bar and computer chip Wires send power between the batteries and screen and computer chip</td> <td>✓</td> </tr> <tr> <td>Computer chip</td> <td>Measures the weight and sends numbers to display screen</td> <td>✓</td> </tr> </tbody> </table>	What are the parts (structures) of the digital scale?	What do you think the structure does (function)?	What are the parts (structures) of the digital load cell?	Metal top	Place to apply force or put the stuff you weigh	Clear plastic top	Batteries	Power source	✓	Buttons (mode/on/off/tare)	Tell it what to do - units/ power/ zero?	microbit buttons ??	Metal bar with wires	Measures weight - when something was put on it, the display output changed and wires send information Senses when a force is applied to it and wires send information	✓ White glue with sensor underneath connected to the computer chip with wires	Display screen	Shows the weight	microbit display ??	Plastic housing	Protects everything, holds everything in place	Clear plastic bottom	Wires	Connect metal bar to computer chip, screen to batteries, computer chip to batteries Wires send signal between the metal bar and computer chip Wires send power between the batteries and screen and computer chip	✓	Computer chip	Measures the weight and sends numbers to display screen	✓
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↓ Navigation to Next Lesson: We decide to record the similarities and differences between how digital and spring scales measure forces. We begin to examine the code that runs a flex sensor.



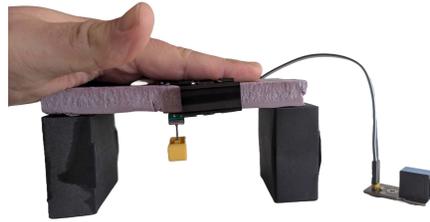
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
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## LESSON 12

3 days

How can sensor systems be designed to differentiate between high- and low-energy collisions to help prevent damage from larger impacts?

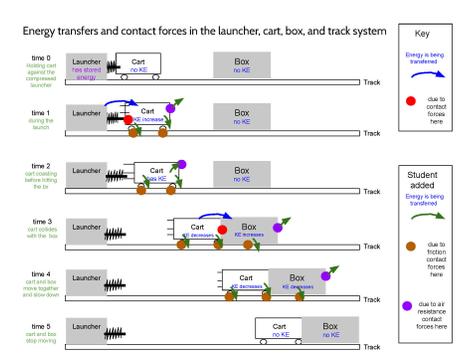
Investigation



Force sensor systems can be developed and calibrated to measure the relative amount of energy transfer in different-size collisions.

We design the code for a force sensor system. We then test whether our code can distinguish between low- and high-energy collisions. We conduct investigations to gather evidence to explain what other forces affect the kinetic energy of an object before a collision. We revise our “Cart-Launcher System” poster to show additional places in the cart-launcher system where energy is transferred and how contact forces cause this energy transfer. We figure out:

- Sensors can be repurposed, using new code, to measure differences in changes of motion to classify the size of collisions.
- 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 the object's 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 (i.e., a temperature increase).
- Energy can be transferred to and from collisions between objects and particles in the air.



Navigation to Next Lesson: We can predict how different structures affect the transfer of energy in our force sensor system, but can we apply these ideas to explain a new phenomenon?

## LESSON 13

1 day

Why do some objects break or not break in a collision and how can sensors help prevent collisions?

Putting Pieces Together



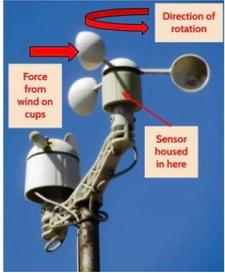
Electronic braking systems are available for bikes that can be triggered by the rider, another person, or automatically by a computer.

We take stock of the questions we can now answer on the Driving Question Board. We apply our ideas, in an assessment, to a new set of collision-related phenomena in the context of an electronic braking system for bicycles. We begin to think about additional design applications. We figure out:

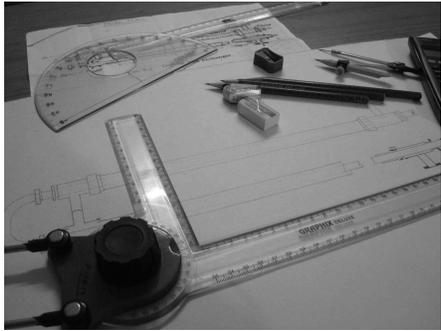
- We have made progress on our DQB questions.
- We can apply our ideas about mass, speed, peak contact forces, and energy transfer to explain automatic bicycle braking systems.



Navigation to Next Lesson: We have made a lot of progress on our ideas for using sensors for force measurement applications. We should try to make some of those ideas a reality.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it									
<p><b>LESSON 14</b></p> <p>1 day</p> <p><b>What criteria should we use to evaluate all the different design solutions we want to build, test, and refine?</b></p> <p>Investigation</p> 	 <p><i>We have different design ideas to measure force in different applications, but need a way to evaluate designs.</i></p>	<p>We identify our design goals for a sensor system and read about how engineers approach designing a sensor system for wind measurement. We identify constraints for our project as a class. We meet with our partners to brainstorm criteria to successfully address design subproblems. We work as a class to develop a list of criteria and how to represent and communicate them. We figure out:</p> <ul style="list-style-type: none"> <li>• Engineers use criteria and constraints to help them design sensor systems for various applications.</li> <li>• Constraints are limitations that any design must follow.</li> <li>• Criteria are specific needs that any design must address.</li> <li>• We can communicate our design thinking to make it visible to others.</li> </ul>	<p>Criteria</p> <table border="1"> <thead> <tr> <th data-bbox="1638 207 1690 227">Sub-System</th> <th data-bbox="1690 207 1795 227">What criteria need to be addressed to successfully design the sub-system?</th> <th data-bbox="1795 207 1890 227">How can we communicate or make our design thinking about the criteria visible to others?</th> </tr> </thead> <tbody> <tr> <td data-bbox="1638 227 1690 365">Hardware</td> <td></td> <td></td> </tr> <tr> <td data-bbox="1638 365 1690 511">Software</td> <td></td> <td></td> </tr> </tbody> </table>	Sub-System	What criteria need to be addressed to successfully design the sub-system?	How can we communicate or make our design thinking about the criteria visible to others?	Hardware			Software		
Sub-System	What criteria need to be addressed to successfully design the sub-system?	How can we communicate or make our design thinking about the criteria visible to others?										
Hardware												
Software												

⚡ **Navigation to Next Lesson:** Now that we have defined our various design goals and identified how to communicate our work, we can work with our partners to finalize our designs using the constraints and criteria.

<p><b>LESSON 15</b></p> <p>3 days</p> <p><b>How does building and (re)testing a prototype of our designs help us refine our design proposals?</b></p> <p>Investigation</p> 	 <p><i>Sensor systems can be used to measure and respond to high winds or other applications.</i></p>	<p>We work with our partners to finalize our designs to work within the constraints and successfully address the criteria we identified in Lesson 14. We work on a subsystem each day and record our process in an engineering design journal. We figure out:</p> <ul style="list-style-type: none"> <li>• An engineering design journal is a tool to help record the iterative process used to test and refine prototypes.</li> <li>• Scientists and engineers use an iterative process when trying to design solutions to real-world problems.</li> </ul>	<p>Final Design</p> <p><b>Write/draw/add photos:</b></p> <p>What was your final design? Add a photo of the physical prototype.</p> <hr/> <p>Add a link to your final code.</p> <hr/> <p>Explain why you chose this version as the final design.</p>
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⚡ **Navigation to Next Lesson:** We feel confident in our designs, but need to seek feedback from our peers.

Lesson Question

Phenomena or Design Problem

What we do and figure out

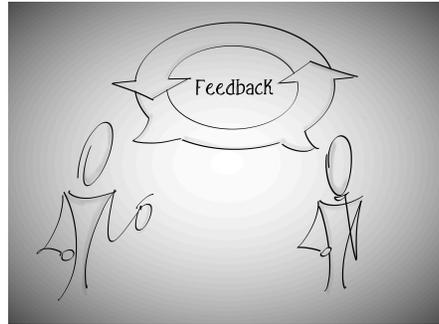
How we represent it

### LESSON 16

1 day

**How can we use feedback from other teams to refine our own designs?**

Putting Pieces Together



*We have different force measurement design ideas that can still be improved.*

We reflect on how our design process compares to the work of professional hardware engineers. Our design team splits up and forms larger groups with students from two other design teams. We share our designs and receive feedback on sticky notes. We meet back with our partner to organize and determine ways we can address the feedback. We figure out:

- Feedback is an important piece of information to guide design refinement.
- Designs can sometimes be strengthened by incorporating aspects of other designs.

**Get Feedback**

**Write/draw/add photos:** After sharing your design and test results, record feedback here.

Observations	Comments of how well design addresses the design challenge	Other feedback
Add names and comments here:		

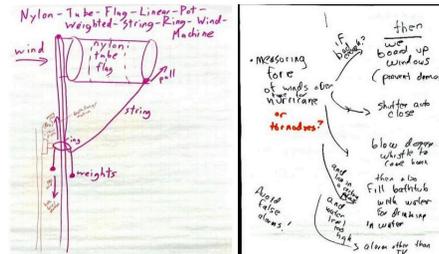
↓ Navigation to Next Lesson: Now that we have received and used feedback from our classmates, we can start to develop a way to communicate our design with other potential stakeholders.

### LESSON 17

2 days

**How can we best communicate our design ideas to others? (Optional)**

Putting Pieces Together



*We have developed different force measurement solutions.*

In this *optional* lesson, we develop a presentation to share our design with community stakeholders. We figure out:

- As a designer, information has to be presented in a relevant and engaging way that shows stakeholders their needs are taken into account.

**Plan your presentation**

Questions	How will you address the feedback in your presentation?
What do you need to communicate about your design and process and which stakeholders (other than teachers in Lesson 16 and other engineers)?	
How will you use visual aids in your presentation?	
What points of your presentation can you adapt from your Engineering Design Journal?	
How will you make sure your design and its benefits are clear to potential investors and other stakeholders?	
What do you know about the stakeholders? How might that impact your presentation?	
Who is going to share which ideas?	
How much of the presentation will you dedicate to each part? To address questions?	

↓ Navigation to Next Lesson: There is no next lesson.

## LESSONS 1-17

32 days total