LESSON 4: How much do you have to push on any object to get it to deform (temporarily or permanently)?

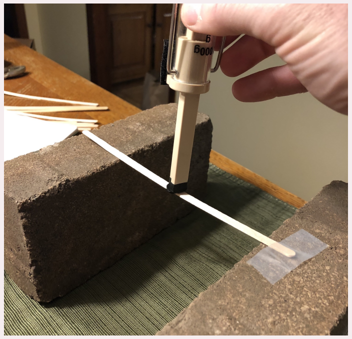
PREVIOUS LESSON

We analyzed slow-motion videos of different objects colliding. We carried out an investigation to determine if seemingly rigid objects bend when contact forces are applied to them. We argued from evidence that rigid objects can also bend or change shape when contact forces are applied to them.

THIS LESSON

INVESTIGATION

3 days



We analyze images from load testing a concrete beam. We plan and carry out an investigation into the relationship of contact force strength vs. the amount of material deformation. We construct graphs of our data and compare them to those from other materials tests. We develop a model to explain and represent the elastic behavior of all solid objects and how larger contact forces lead to larger amounts of deformation up to a point, beyond which further deformation damages the object (permanently deforming it and/or breaking it apart).

NEXT LESSON

We will carry out investigations to explore what happens when two objects come in contact with each other to learn that each object applies a force on the other object. We will then investigate how different speeds and masses of objects that collide affect the amount of force on each object. We will argue from evidence that the amount of force is the same on each object, regardless of the speed or mass of each object.

BUILDING TOWARD NGSS

MS-PS2-1, MS-PS2-2

WHAT STUDENTS WILL DO

Plan an investigation identifying controls to keep constant **and carry out the investigation** to produce data to serve as the basis for evidence that will be used to develop a mathematical model that describes the relationship (pattern) between the amount of force (cause) applied to an object and the amount it deforms (stability and change, effect).

Analyze and interpret data to provide evidence. Construct graphical displays of data from compression force vs. deformation tests to help identify a linear relationship (pattern) that describes the elastic behavior of all objects up to a specific limit, beyond which additional deformation results in damage.

WHAT STUDENTS WILL FIGURE OUT

All solid objects deform elastically when smaller amounts of force are applied to them; they will spring back to their original shape when this force is removed.

How much a solid object deforms for a given amount of force applied to it is dependent on the type of material it is made of, its shape, and its thickness.

Different objects have a different elastic limit, which is the maximum amount of deformation they can withstand, beyond which they deform permanently.

Different objects have a different breaking point, which is the maximum amount of deformation they can withstand, beyond which they will crack (fracture).

Lesson 4 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	8 min	**NAVIGATION AND PREPARE TO INVESTIGATE OUR PREDICTIONS** Connect to the prior lesson and introduce a way that engineers test a material to see how much it deforms in response to a force applied to it.	A-B	computer and projector,
2	8 min	**ANALYZE CONCRETE LOAD TESTING PHOTOS** Show a series of photographs of the results from load testing a concrete beam. Have students analyze these for evidence of deformation.	C-K	computer and projector,
3	7 min	**PLAN THE MATERIALS TESTING INVESTIGATION** Introduce the materials students will use in the investigation and demonstrate what the push-pull spring scale measures.		Material Deformation Equipment Demonstration
4	7 min	**IDENTIFY THE VARIABLES IN THE INVESTIGATION** Discuss what the independent, dependent, and controlled variables would be for this investigation.	L	*Independent, Dependent, and Controlled Variables*, *Results*, *Results from other materials tests*, chart paper, markers, computer and projector,
5	15 min	**CARRY OUT THE MATERIAL DEFORMATION LAB** Monitor student group work in their material deformation investigation lab.	M	*Independent, Dependent, and Controlled Variables*, *Results*, *Results from other materials tests*, 2 bricks, push-pull spring scale (10 N), metric ruler, piece of packing tape, pieces of scotch tape, ~4 wood coffee stirrers or rice noodles, computer and projector, Material Deformation Lab
				End of day 1
6	2 min	**CHOOSE A FOCAL NORM** Students select a norm to work on in this lesson.	N	*Independent, Dependent, and Controlled Variables*, norms poster, computer and projector,
7	12 min	**ANALYZE GRAPHS AND DEVELOP LINES OF BEST FIT** Introduce the additional data that was collected and show how to find a trend line. Use the jigsaw strategy to have students compare lines of best fit between the different materials they tested.	O-S	ruler (or straight edge, like a coffee stirrer), computer and projector, tape,
8	10 min	**GATHER INFORMATION FROM OTHER ENGINEERS** Introduce data students will use to update their individual Progress Trackers.	T	*Results from other materials tests*, computer and projector,
9	18 min	**ADD TO OUR PROGRESS TRACKER** Lead a Consensus Discussion to update the class Progress Tracker.	U	*Progress Tracker*, chart paper, markers, computer and projector,
10	3-5 min	**REFLECTING ON NORMS** Assign exit ticket and collect them to gauge student perception of progress toward developing class norms.	V	index card or separate piece of paper., norms poster,
				End of day 2

Lesson 4 • Materials List

	per student	per group	per class
Material Deformation Equipment Demonstration materials			• 2 bricks • 3 wood stirrers taped together • tape • a ruler • class set of 10N push-pull spring scales • a digital scale
Material Deformation Lab materials		• 2 bricks • 4 wood stirrers or pasta pieces • tape • ruler • the entire set of push-pull spring scales (10 N)	• tape
Lesson materials	• *Independent, Dependent, and Controlled Variables* • *Results* • *Results from other materials tests* • science notebook • ruler (or straight edge • like a coffee stirrer) • *Progress Tracker* • index card or separate piece of paper.	• 2 bricks • push-pull spring scale (10 N) • metric ruler • piece of packing tape • pieces of scotch tape • ~4 wood coffee stirrers or rice noodles	• computer and projector • chart paper • markers • norms poster • tape

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Make one single class set of *Investigation Procedures* to reuse across classes.

Make a double-sided copy of *Results from other materials tests*, one per student.

If you are using science notebooks (9.75" x 7.5") and you have a paper cutter, trim all handouts to fit in the notebooks.

You only need to copy one of for every 2 students. Trim it in half to make two pieces to hand out from every piece of a paper.

Day 1: Material Deformation Equipment Demonstration

- **Group size:** Whole class
- **Setup:**
    - Put two bricks on lab table, 14 cm apart.
    - Tape 3 coffee stirrers together on both ends (using scotch tape).
    - Leave a piece of packing tape out for taping down the stirrer.
    - Take out a class set of push-pull spring scales (10 N) to use.
    - Take out a digital scale to use.

- **Storage:** All materials can be stored and reused indefinitely.

Day 1: Material Deformation Lab

- **Group size:** 3 students
- **Setup:**
    - Leave two bricks and one ruler at each testing station.
    - Leave common supplies in one area: rice noodles, wood stirrers, and tape.
    - Students will take one push-pull spring scale (10 N) to their lab station.
- **Safety:** Make sure students wear impact goggles (or splash goggles).
- **Disposal:** Used coffee stirrers and rice noodles can be thrown away in the trash.
- **Storage:** All materials can be stored and reused indefinitely.

Lesson 4 • Where We Are Going and NOT Going

Where We Are Going

Most solid objects that are made of material that is relatively stiff don't appear to exhibit elastic behavior to the unaided eye. However, such objects actually are elastic (up to a point) when measured at a different scale. All solid objects are springy or elastic (up to a point). Forces can be applied to them and they will change shape, and they will spring back to their original shape when those forces are removed, as long as those forces don't exceed that object's elastic limit. Not many materials are elastic beyond a small amount of deformation.

The elastic limit of an object is dependent on its material type and its thickness. Once applied forces exceed that elastic limit, permanent deformation occurs in the object. This can be thought of as a type of damage. If external forces on the object increase further, they will eventually reach the breaking point of the object (where fracturing occurs). Different materials have different elastic limits and different breaking points.

The relationship between the force applied to an object and the amount it deforms when it exhibits elastic behavior is linear for all solid objects. The slope of this relationship is different for different types of materials. For example, a 1 cubic inch sample of rubber in the shape of a cube will deform 0.0001 inches per 1 lb of compression force applied to it, steel will deform 0.0001 inches per 30,000 lbs of force applied to it, and diamond
will deform 0.0001 inches per 1700,000 lbs of force applied to it.

The region of elasticity of all solid objects helps explain why objects push back on things that push on them. It provides a mechanism for explaining why objects in contact exert equal and opposite forces on each other, why collisions can cause changes in motion in the objects that collide, and why objects are damaged in some cases but not damaged in others.

Where We Are NOT Going

The linear relationship between force and deformation is not a disciplinary core idea. The spring-like behavior of solids, though, is cited in the Framework for NGSS: "The role of forces between particles also begins to be discussed in grade 6--topics include the recognition that particles in a solid are held together by the forces of mutual attraction and repulsion (which act like springs)" (p. 237).

Working with linear and non-linear relationships in general are a target of one element of the SEP for analyzing and interpreting data in the middle grade bands. It is also a target of the CCMS in 8th grade. This lesson is the first introduction to working with linear and non-linear relationships in graphs in OpenSciEd. Students will revisit the use and development of other linear and non-linear models for data they collect later in this unit and in subsequent 8th grade units: Unit 8.2 (Sound) and Unit 8.3 (Forces at a Distance).

The elastic limit of an object is not only dependent on its material type and its thickness, but it is also dependent on the cross-sectional area that the compression or tension force is applied to. No attempt is made to introduce this idea, which is connected to the ratio of stress to strain an object exhibits during elastic behavior (Young's Modulus of Elasticity). Known values of the ratio of force vs. deformation for elastic behavior of known materials based on Young's Modulus of Elasticity were derived for 1 cubic inch samples in the shape of a cube for the table used in *Results*. Force and deformation data used in *Results* were extrapolated from machine-produced curves reported in Nikita Khlystov, N., Lizardo, D., Matsushita, K., and Jennie, Z. (2013). *Uniaxial Tension and Compression Testing of Materials 3.032 Lab Report.* Retrieved from http://web.mit.edu/dlizardo/www/UniaxialTestingLabReportV6.pdf

Engineers typically graph force vs. deformation (or stress vs. strain) with force per unit area being plotted on the x-axis of a graph and the ratio of deformation divided by the original object's length being plotted on the y-axis. One reason for this is that it allows easy calculation of potential energy stored in the object (by integrating the area under curve of stress vs. strain). None of this is a target idea in this lesson, nor is it a target idea in high school in the NGSS. However, we wanted to make teachers aware of the rationale for the established engineering convention and why we flipped the axis that force and deformation are displayed on in this lesson. In this lesson, where force is the independent variable and deformation is the dependent variable, force is plotted on the x-axis and deformation is plotted on the y-axis, as per experimental design conventions.

Students are introduced to qualitative fitting of a trend line to a scatter plot of data in this lesson. No attempt is made in this or other 8th grade OpenSciEd units to use linear regression to find this line. This is well beyond the grade band. No attempt is made to calculate the slope of this line, though qualitative comparisons of slopes of such lines is highlighted in *Results*.

LEARNING PLAN for LESSON 4

1 · NAVIGATION AND PREPARE TO INVESTIGATE OUR PREDICTIONS

8 min

MATERIALS: computer and projector

Connect to the prior lesson. Show **slide A**. Read through the text at the top of the slide. Point out that the text introduces the word **"deform,"** which means to distort, bend, or change the shape of something in any way, either temporarily or permanently. Read through the question on the slide and say that you want to take a poll of students who think yes and no for each example.

Introduce one way engineers test materials for this. Say, *Let's think more about how we could test these predictions further*. Show **slide B**. Say, *The photo to the right shows one way that engineers test the relationship between the amount of force applied to an object and the deformation that occurs in that object. They have tested all kinds of materials this way. Steel pipes, copper or aluminum bars, even materials as hard as concrete or diamond. In this photo, engineers are doing such a test with large concrete beam. They increase the amount of downward force they are applying to the top of the beam to see how it will respond.*

Point out where the machine they are using is pushing downward on the beam. Read the prediction question and give students a couple of minutes to discuss it with a partner.

After students have discussed, animate the slide, and propose that the question on the slide (**"How much do you have to push on any object to get it to deform?")** is the question we have some competing predictions for and that we want to try to figure out an answer to in this lesson. Write this question on the board as well. You will refer to it when students set up the variables to change and control for their lab.

2 · ANALYZE CONCRETE LOAD TESTING PHOTOS

8 min

MATERIALS: computer and projector

Analyze the results from the concrete testing. Tell students that you are going to show them a series of photos that show how the concrete beam responded to increases in the amount of downward force applied to it; however, the changes in the beam, just like those in the table or glass we tested with the laser, will be subtle and will be easier to see if they gather around closer to the projected image.

Have students form a semicircle around the projected image as you move from **slide C** to **slide D**, saying, *The engineers are applying a greater amount of downward force in this slide.* Repeat that statement for each slide you move forward to. Ask students to describe any changes they noticed in the beam when you moved from **slide C** to **slide D**. Move backwards and forward between these two slides. Have students share what they noticed. Encourage them to point to changes they see at spots on the beam as they describe them so others can understand what part of the system they are referring to. Repeat this for **slide D** to **slide E, slide E** to **slide F**, etc. all the way until you reach **slide J**. Then reverse the slides again and move through the series again without discussion.

Say, *OK, we've seen the results from testing one type of object made of one type of material. What would we say happens to the amount of deformation that object experienced as the amount of force applied to it increased?*

Students should say the amount of deformation increased as force increased. Say, *We may not have evidence, though, for whether any of that deformation was temporary. It seems like once we say it started to crack or fracture, that would be part of a permanent shape change in the material, but before we see that crack, we don't know whether the concrete would spring back to its original shape like the table or the glass did after we pushed down on it just a little bit and then removed that force on it.*

Show **slide K**. Have students turn and talk about the question on the slide with a partner. After a couple of minutes, have students share their ideas for the last question.

Suggested prompt	Sample student response
How could we test whether the type of material or how thick the object is affects how much it deforms when a force is applied to it?	*We could try and do something like the engineers did in the photos. We could push down on the material different amounts and measure how much it deforms.* *We could try this for different materials and different thicknesses of materials.*

Say, *I have some materials like the ones you are suggesting that I brought in for us to use. Let's see how we could use them to do some of the things you suggested.*

3 · PLAN THE MATERIALS TESTING INVESTIGATION

7 min

MATERIALS: Material Deformation Equipment Demonstration

Introduce the materials and how they can be used for the investigation. Go through the steps below with students still standing around a demonstration table.

Show that we have bricks available that materials can be positioned on to test how much they deform, similar to how the engineers in the video set up the concrete to test.

Introduce push-pull spring scales. *We have tools scientists, engineers, and others use to determine the amount of force called push-pull spring scales. They have been used to weigh things like luggage, fish you catch, and produce at the market. Let's see if we can use them to determine the amount of force we can put on an object.*

Pass around a push-pull spring scale (10 N) to groups of two or three students.

ADDITIONAL GUIDANCE

Note that these push-pull spring scales can be calibrated by turning the white knob. Before you pass these out, you may want to just double-check they all read 0 when they are held with the hook end down.

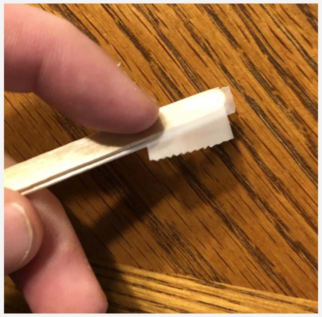
Suggested prompt	Sample student response
Take one spring scale and push on the rod. What happens to the amount of force you feel when you push on it further?	*It feels like more force back on you the further you push the spring in.*

Suggested prompt	Sample student response
What do you notice about the numbers on the spring scales?	*When you push it in further, you feel a bigger force and the numbers show a bigger number.*

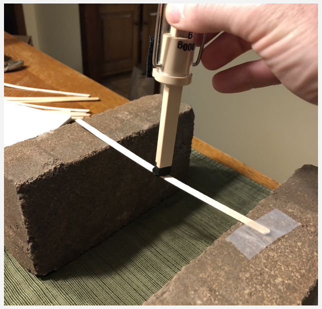
Introduce force units. Say, *In science, we like to describe our numbers with units when we can, like meters, feet, seconds, and hours. Some engineers measure the amount of force in pounds. We will use newtons. Your push-pull spring scales have markings on them that range from 0 to 10 newtons (N). Let's see how many pounds of force correspond to 1 N vs. 2 N vs. 4 N on the scale.*

Demonstrate how the amount that registers on the push-pull spring scale (10 N) corresponds to a similar change that would be registered on digital scale measuring the force from the weight of an object on it. Demonstrate that pushing down with 5 N force results in a measured force that is the same as a weight of just over a pound (~1.1 lbs). Push down with 10 N and show that the weight on the scale doubles to about 2.2 lbs. Emphasize that both scales--the push-pull spring scale and the digital scale--are force measurement devices.

Explain that they can use this scale to apply more or less force to the object they are testing. Say that you are going to demonstrate the kind of testing we could do with an example object--a 3-layer thick beam of wood. Show the set of three coffee stirrers that you taped together. Explain that different groups will be assigned different thicknesses of wood or pasta to test them in a manner similar to what you are going to show.



Place the push-pull spring scale on the beam and push down on it with 2 N force. Ask students what they notice. They should say it deforms. Explain that we have ruler we can use to measure how much it deforms, too.



Say, *Let's use what we've seen about this equipment to set up the variables in our experiment we want to change, measure, and control.*

4 · IDENTIFY THE VARIABLES IN THE INVESTIGATION

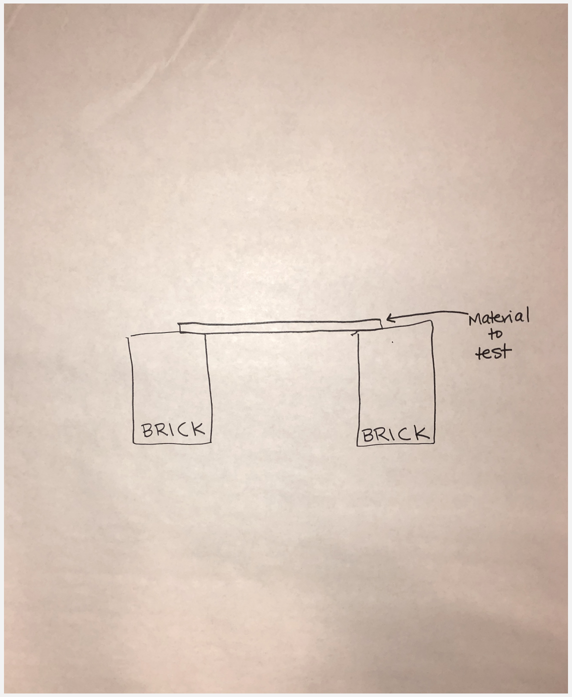
7 min

MATERIALS: *Independent, Dependent, and Controlled Variables*, *Results*, *Results from other materials tests*, science notebook, chart paper, markers, computer and projector

Identify the variables in the investigation. Hand out a copy of *Independent, Dependent, and Controlled Variables* and *Results*. Have students take this back to their seats now and attach both sheets to their notebooks and continue planning the rest of the investigation. You may want to ask them to keep *Results* separate from their notebooks for now if you plan to collect it at the end of the period.

Ask students to refer back to the question we wrote up on the board earlier (**"How much do you have to push on any object to get it to deform?")** and record it as the question we are investigating on their copy of *Independent, Dependent, and Controlled Variables*. Show **slide L.**

Draw a sketch of the beam they will be testing between two bricks on the board or poster paper.



Discuss what the independent and dependent variables would be for this experiment. Review what independent and dependent variables are in general as needed, using the text on *Independent, Dependent, and Controlled Variables* to review.

Create an anchor chart of the definitions from *Independent, Dependent, and Controlled Variables* on the board:

- Independent variable - this is the variable to change each time you test.
- Dependent variable - this is the variable to observe the effects caused by a change in the independent variable.

Use the supplementary text in italics to further explain what these are:

- Independent variable - this is the variable to change each time you test. *This is what you are manipulating in the experiment*.
- Dependent variable - this is the variable to observe the effects caused by a change in the independent variable. *This is the results variables*.

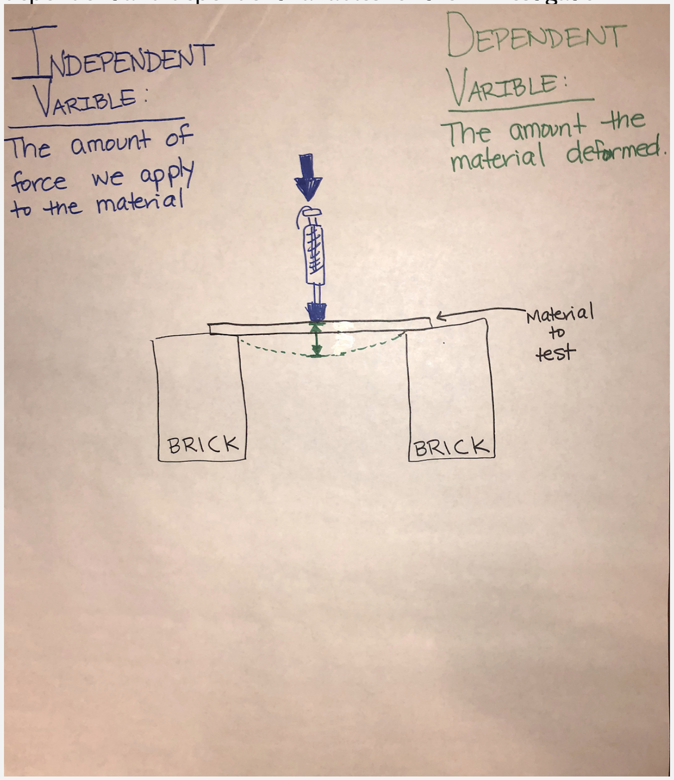
Post and save a copy of this anchor chart for students to refer to in this unit and future units. ✱

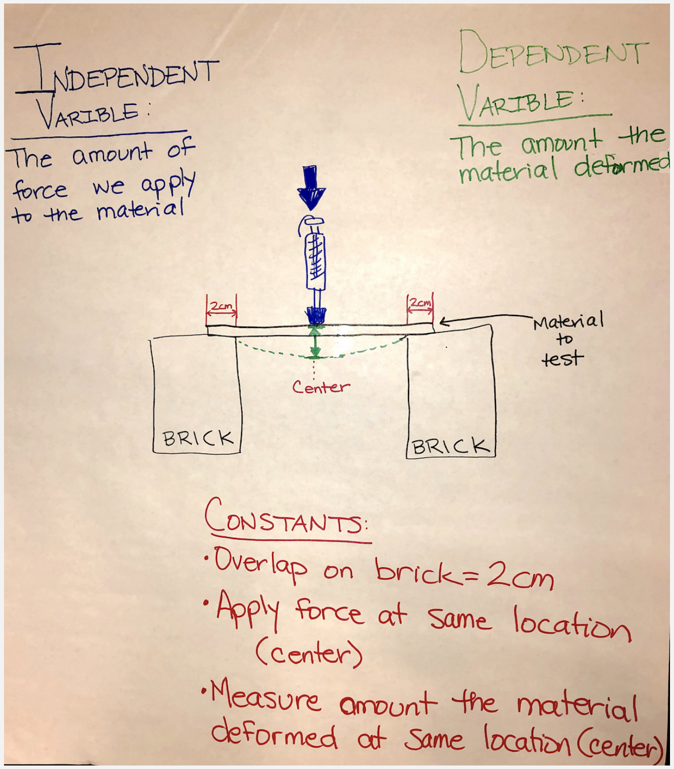
ADDITIONAL GUIDANCE

Students will be planning other investigations by identifying these variables in future lessons in this unit and in other units in this grade. Having an anchor chart and their copy of *Independent, Dependent, and Controlled Variables* will be helpful references for students at the start of the year. If students are struggling with these ideas, you may need to review some examples from previous investigations they have done in prior years. OpenSciEd units will have multiple examples to draw from in Unit 6.2 (Thermal Energy), 6.3 (Weather), 7.1 (Chemical Reactions), 7.3 (Metabolic Reactions), and 7.4 (Matter Cycling).

Students should say that the independent variable is how much we push on an object and that the dependent variable is how much it deforms.

Point out that we have a way to measure the amount of push by reading the amount of newtons on the push-pull spring scale. Ask for ideas about how to measure how much the object bends or deforms. Help students narrow in on the idea of recording the height of the beam before and after you push on it. Once you do, add these to the sketch you are making and have students record these as the independent and dependent variables for their investigation.





Discuss some things that would be important to keep constant in the investigation. If students don't suggest the placement of the object and the scale as things to keep constant, ask if the location of the spring scale would affect the results and if the distance between the bricks would affect the results. Then suggest that all groups test their objects in the center of the beam and make sure that their beams overlap the bricks the same amount. A 2 or 3 cm overlap is suggested. Whatever you pick as a class, write the measurement down on the sketch of the system you made. Have groups record these variables to keep constant on *Independent, Dependent, and Controlled Variables*.

Assign groups a different material to test. Have students record which material you assigned them to test in column A of *Results*. The different options include: a single coffee stirrer, two coffee stirrers stacked together, a single rice noodle, or two rice noodles stacked together. Explain that groups can use extras of these if the one they are testing fractures or cracks.

Pass out a copy of *Results from other materials tests* to students. Show **slide M**. Tell students to use this procedure to record the data from their investigation. Give students a couple of minutes to look through the procedure and then ask if there are any questions.

5 · CARRY OUT THE MATERIAL DEFORMATION LAB

15 min

MATERIALS: Material Deformation Lab, *Independent, Dependent, and Controlled Variables*, *Results*, *Results from other materials tests*, science notebook, 2 bricks, push-pull spring scale (10 N), metric ruler, piece of packing tape, pieces of scotch tape, ~4 wood coffee stirrers or rice noodles, computer and projector

Monitor lab work. Check to see that groups are involving all members in the data collection. This is a lab that requires at least 3 different roles in the data collection process.

Optional: Collect ***Results*** from students before they leave.

ASSESSMENT OPPORTUNITY	Students will be developing coordinate graphs across the first three units of 8th grade (8.1, 8.2, and 8.3) in OpenSciEd. As this is the first unit in the 8th grade sequence, here is a good opportunity to formatively assess students' fluency in plotting coordinate values in the first quadrant.

End of day 1

6 · CHOOSE A FOCAL NORM

2 min

MATERIALS: *Independent, Dependent, and Controlled Variables*, science notebook, norms poster, computer and projector

Choose a norm to work on in this lesson. Show **slide N**. Give students a minute to look through the class norms.

ADDITIONAL GUIDANCE	The second day of this lesson is a strategic point to have students revisit their class norms. This lesson was selected for this because the first half requires some communication and coordination with members from other groups. The last part of it requires students to participate for an extended amount of time in whole-class discussion in the Scientists Circle. During days where there is a large whole-class discussion in the Scientists Circle, you can choose to add this step of picking a focal norm to launch the lesson and wrap it up even if it isn't written into the teacher guide. It is recommended that you add in a similar revisiting of classroom norms at such strategic places in each OpenSciEd unit you teach, places where you envision you could carve out an extra couple of minutes at the start of that day of the lesson and a few minutes at the end of that day in the lesson to reflect (and debrief as a class as time permits). It is recommended you look for opportunities to do this at least once a week across your first unit of study.

7 · ANALYZE GRAPHS AND DEVELOP LINES OF BEST FIT

12 min

MATERIALS: ruler (or straight edge, like a coffee stirrer), science notebook, computer and projector, tape

Introduce the additional data that was collected. Ask students to look back at the data they collected from the last class. Ask for a show of hands if they collected data for wood stirrers vs. pasta. Ask for a show of hands if they collected data for a single piece of their material. vs. two pieces of their material.

Say, *You all plotted the data from the material you tested. I want us to talk about how we might develop a mathematical model of the relationship we see in your data. I have a set of data for us to look at together.*

Present **slide O.** Explain that this data was collected from three wood stirrers taped together. Give students a minute to look at the graph and then ask them to share what patterns they notice. Help students reason out why there are multiple points for certain x-values.

Suggested prompt	Sample student response
What patterns do you notice in the data?	*The data looks a bit scattered.*
What tends to happen to the amount of deformation as the force applied to this object increases?	*It tends to increase.*
Where on the graph do we see evidence of having recorded more than one measurement for a specific amount of force?	*At 2 N.* *At 5 N.*

Describe what a trend line is and how to make one. Say, *When you have multiple data points and some of them are for the same value you used for your independent variable, it can be helpful to plot all that data on a coordinate graph. What we end up producing is called a scatter plot. Because we haven't averaged any of our results yet, it can also be useful to think about what the average trend in the data is. One way to do this is to create a trend line to show how close the data are to a linear relationship. Constructing a trend line can be done by holding up a ruler or straight edge over the graph and shifting the slope and y-intercept of the line made by the straight edge around until it is as close as possible to all the data points on the graph. This line may pass through some of the points, none of the points, or all of the points. The key is to try to fit the line as close as possible to the average trend in the data.*

Compare lines of best fit. Show **slide P**. Ask which line is a better fit to the data. Students should say line C.

Explain that this trend line is also sometimes called the "best fit line." It helps us see that the data might be closer to a linear relationship than we suspected at first. Maybe with more data, we would see an average trend that looks very close to this line. Add "best fit line" to the word wall along with a sketch (or printout) showing an example of what one looks like (e.g., line C from **slide P**).

Ask for a show of hands for students who think they will see a pretty good fit of their data to a linear relationship if they also drew a line like this through the average trend in the data they graphed last time. Accept all responses.

Construct trend lines for the data that students collected. Tell students, *Sometimes data that doesn't look that linear ends up looking much more so after we draw a best fit line. Let's see what that looks like for your data now.* Show **slide Q**. Give students a minute to construct best fit lines for their own data using a ruler (or coffee stirrer) and a pencil or pen on *Results*.

Jigsaw groups. Show **slide R**. Ask all students who investigated a single coffee stirrer to raise their hands. Count off by number and have them remember their number. Do the same for the students who investigated two coffee stirrers. Do the same for single rice noodles. Do the same for double rice noodles.

Instruct students to relocate in their groups to compare graphs. Give students about 3 minutes to compare and discuss what they notice in the different graphs.

Make predictions. Show **slide S**. Read the text on the slide. Point out that the compression machine they used is shown in the photo. Have students turn and talk about their predictions. As students are doing this, hand out a copy of *Results from other materials tests* to each student.

8 · GATHER INFORMATION FROM OTHER ENGINEERS

10 min

MATERIALS: *Results from other materials tests*, science notebook, computer and projector

Introduce the context of the reading. Emphasize that *Results from other materials tests* will summarize the results from the materials testing predictions they made with a partner. Show **slide T**. Instruct students to read and answer the questions on *Results from other materials tests* individually. Tell them that you want to collect this at the end of the period and that the last instruction in the reading is to update their individual Progress Trackers. Tell students that they should include anything they figured out from the lab and the reading that helps answer our lesson question when they get to that point as we are going to share our discoveries in a Scientists Circle after this.

Give students the remaining time to work on this individually.

9 · ADD TO OUR PROGRESS TRACKER

18 min

MATERIALS: *Progress Tracker*, science notebook, chart paper, markers, computer and projector

Lead a Consensus Discussion. Show **slide U**. Pass out a copy of *Progress Tracker*. Have students attach this to their notebooks. Relocate in a Scientists Circle.

Have students rewrite the question(s) that we were investigating on their copies of *Progress Tracker*.

Remind students that we first started looking into this question by looking at slow-motion collision videos of cars, a baseball bat, and a golf ball. Ask students what additional sources of data we used to investigate this question since then. Students should recall four other sources of data. Help students agree on this list to add to their Progress Tracker:

- slow-motion videos of collisions (cars, golf ball, bat)
- laser light reflected off flexible stick-on mirror material on a sponge, a piece of glass, and a table
- concrete load test images
- force vs. deformation lab results (wood and noodles)
- compression test results from other engineers

Shift to co-developing a list of key ideas that we figured out from our work with these sources of data. Have students look back at what they wrote in their individual Progress Trackers for ideas. Use suggested prompts similar to these, inviting students to contribute ideas and to work with the ideas that others contribute:

- *Who can suggest one idea we should add to our Progress Tracker about how materials respond when a force is applied to them?*
- *Is this true for all solids? How do we know?*
- *Can someone summarize an important idea about what it means when we say solids are elastic up to a point?*
- *If all materials are elastic up to a point, what is the difference between a rigid material like steel or glass and something that is more flexible?*
- *Does someone have an important idea about elastic limit or breaking points related to forces that we haven't included yet in our class Progress Tracker?*

Use follow up prompts like *Do you agree? Did anyone say the same idea in a different way?* to encourage students to voice agreement on ideas.

KEY IDEAS

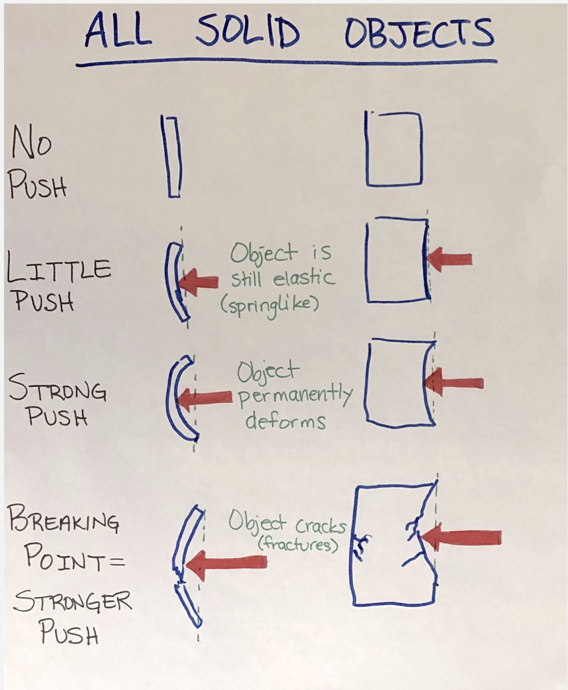
Purpose of this discussion:

- Summarize the main ideas about how solid objects respond to forces applied to them and how their elastic limits and breaking points are affected by the material they are made of, their shape, and thickness.

Listen for and have students make note of these ideas on their Progress Tracker:

- (From previous lesson): All solid objects bend or change shape in a collision and when other contact forces are applied to them.
- All solid objects deform elastically when smaller amounts of force are applied to them; they will spring back to their original shape when this force is removed.
- How much a solid object deforms for a given amount of force applied to it is dependent on the type of material it is made of, its shape, and its thickness.
- Different objects have a different
  - **elastic limit =** the maximum amount of force or deformation they can withstand, beyond which they will deform permanently.
  - **breaking point =** the maximum amount of force or deformation they can withstand, beyond which they will crack (fracture).

In addition to a summary of the ideas listed in the key ideas section, have students add a visual representation of the ideas to their Progress Trackers like the one shown here:



If time permits, invite students to explain how these ideas help us answer our driving question. Use prompts like these:

- *Can someone summarize how these ideas help us explain why some contact forces damage objects and others don't?*
- *How could these ideas help explain why some collisions might cause damage and others don't?*

Listen for student responses related to the amount of force applied, the amount of deformation that it causes in the material, and whether the force exceeds the elastic limit of the object and/or its breaking point.

10 · REFLECTING ON NORMS

3-5 min

MATERIALS: index card or separate piece of paper., norms poster

Assign Exit Tickets. Show **slide V**. Have students write their responses to the questions shown on the slide on an index card you pass out to each student or on a separate piece of paper.✱

ADDITIONAL GUIDANCE	This sort of exit ticket can help you gauge students' perceptions related to their classroom culture and help you identify opportunities to revisit the data that students provide you as an entire class. Such exit tickets can be modified too, to ask about things like: • Did you share any ideas out loud today to the whole class, a small group, or a partner? • Did you learn more in class today because other students shared their ideas or opinions? • What can our learning community do to help encourage everyone to share their ideas? This sort of feedback can provide insights into potential barriers for access and equity for some students that you can address. It can also help students reflect on the importance of sharing and working with each other's ideas.

Additional Lesson 4 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	**CCSS.ELA-LITERACY.SL.8.1.C** Pose questions that connect the ideas of several speakers and respond to others' questions and comments with relevant evidence, observations, and ideas. **CCSS.ELA-LITERACY.SL.8.1.D** Acknowledge new information expressed by others, and, when warranted, qualify or justify their own views in light of the evidence presented. Both of these ELA goals are the focus of the discussion in the Scientists Circle at the end of day 2 of this lesson when the class is working together to decide how to update their Progress Tracker. The focus on connecting questions, sources of evidence, what we observed, and key science ideas from other students in order to create an agreed-upon set of consensus ideas to add to the Progress Tracker relies on the first ELA goal above. The framing for the second day of this lesson, where students pick a norm to focus on at the start of the period and then reflect on individual and class progress toward it in the exit ticket, is designed to support the second ELA goal above. Use student responses from their exit tickets to revisit, reinforce, or refine norms for collegial discussions as needed at the start of the next lesson.

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH	**CCSS.MATH.CONTENT.8.F.B.4** Construct a function to model a linear relationship between two quantities. Determine the rate of change and initial value of the function from a description of a relationship or from two (*x*, *y*) values, including reading these from a table or from a graph. Interpret the rate of change and initial value of a linear function in terms of the situation it models and in terms of its graph or a table of values. **CCSS.MATH.CONTENT.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). Both of these math goals are a focus of the end of day 2 of this lesson when the class is working together to determine a trend line for a set of data (material deformation due to compression force). Students make a similar line for the data they plotted the previous day and compare this to the lines of best fit made for other data sets from other groups. Students also compare graphs of linear relationships for the elastic behavior of other materials and non-linear regions in the graph as well. They interpret the graph to identify the point that the elastic limit of the object is reached and its breaking limit. They also interpret a table of values describing the slope of the graph for the elastic behavior of the different materials as the ratio of material deformation in inches for a certain amount of compression force.