Physical models of strain

Nancy West and Shelley Olds, expanded from work by Vince Cronin

In these five activities, students measure and observe strain in physical models. Students explore strain in one-dimension using bungee cords and compressional springs in the first two activities. The third activity is two-dimensional with a high-tech, high-performance athletic tee shirt. The fourth demonstrates pure strain with Silly Putty®, and the last shows simple strain in two-dimensions (essentially), using a stack of cards.

Instructor's notes

These activities provide an intuitive understanding of strain from which you can develop the concepts and vocabulary students need to interpret vectors derived from high resolution GPS time-series data. Students will draw on their experience with physical models to make sense of quantitative data and analyses. They will build towards an understanding of crustal strain as a component of crustal deformation. A bungee cord becomes the first brick in the road to interpreting strain within a regional tectonic setting.

Students work in pairs or small groups in these activities. We recommend that students do the activities *before* you provide formal explanation. Your discussion will be both livelier and more likely to stick with your students if they have explored the models and formed their own tentative understanding. You can then formalize the concepts and language with a discussion or presentation. PowerPoint presentations are available to complement the activities.

We also suggest that you first explore one-dimensional strain in its entirety and then move onto two-dimensional strain. That is, have students explore the one-dimensional models (bungee cords and springs) and then reinforce their understanding of extension and stretch with a discussion. You can provide "Strain—for students" as a supporting text on one-dimensional strain. Then move on to two-dimensional strain with the tee-shirt model, followed by discussion and readings, and finally the activities with Silly Putty® and a stack of cards, followed by explanation.

Lab sheets for the five activities follow. You will want to decide whether to expect one lab sheet for the entire group or one from each student.

<u>Preparation for Activity 1: Bungee cords</u>

This activity requires a set-up with a bungee cord (or sewing elastic) on a rigid platform (Fig. PM.1.) The bungee must be marked in two places with black thread and one in red. A centimeter ruler lies alongside the bungee, with the zero-end at the first black thread. Note that the board backing has two hooks on the right side, and that the left end is firmly affixed with a heavy-duty staple.

Materials: an apparatus for each group, tape (to affix the ruler to the board), worksheets.

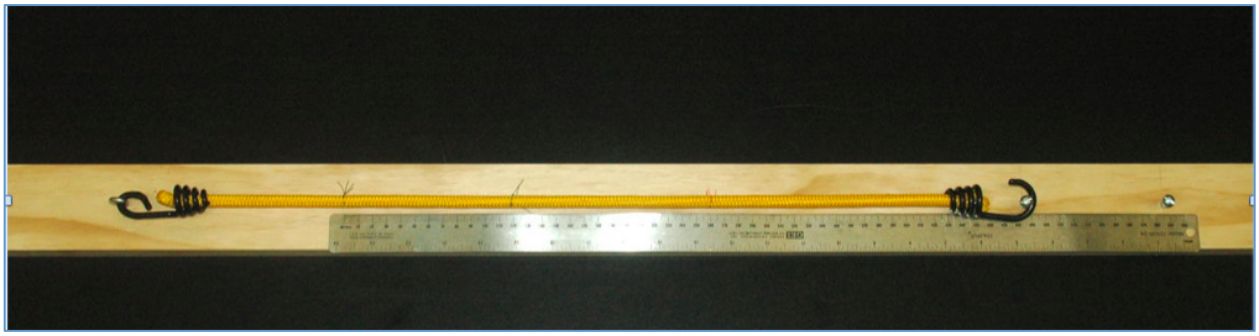

Figure 1. Example of the apparatus for Activity 1. Black threads are sewn around the cord on the left side. A red thread is sewn about 2/3 of the way to the right. Cronin, 2012.

Preparation for Activity 2: Compressional springs

This activity is written so that students design their own methods for measuring extension (which plays out as shortening) with compressional springs.

Materials: a variety of compressional springs, rulers, and other materials that students request.

Figure 2. Compressional springs under hobby horses at an Italian playground. Cavallini da gioco. Lucarelli, 2009.

Preparation for Activity 3: Tee shirts

This activity requires a piece of fabric that stretches well in two-dimensions. You can use the front or back of a compression tee shirt from an athletic or discount store. Buy the largest you can find. (Wikipedia or Google can help you find brands of compression apparel.) Draw a circle on the fabric with a permanent marker (Fig. 3).

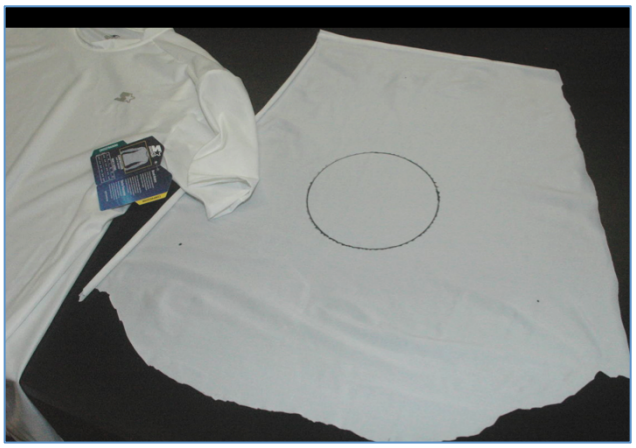

Figure 3. Tee shirt fabric with circle. Cronin, 2012.

Materials: For each group, a tee shirt marked with a circle, worksheets.

Preparation for Activity 4: Silly Putty®

This activity requires students to play with Silly Putty® in order to understand pure strain. You can purchase traditional eggs of it at most toy stores or you can buy it in bulk from the Crayola store. ("Bulk" equals five pounds. Think of the fun you can have….) Students will roll a handful of Silly Putty® into a cylinder and then press an open vial or small jar into the side of it. They will stand the cylinder on end, and wait and watch. (Figs. 4 a, b, and c.)

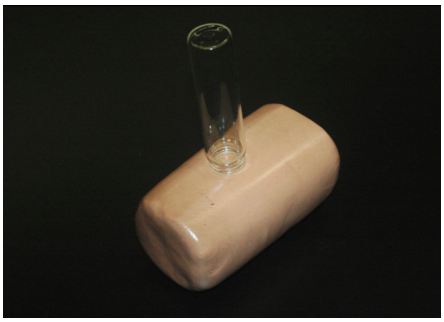

Figure 4a. Preparing

Figure 6b. Before

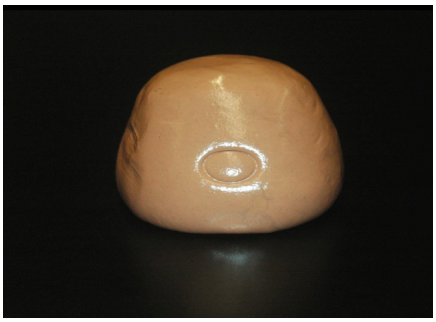

Figure 5c. After. Cronin, 2012.

Student groups could do this while they do Activity 4, or you could do this as a demonstration—if say, you're limited in the amount of Silly Putty® on hand.

Materials: For each group, Silly Putty®, a metric ruler, a small vial or bottle, time, worksheets.

Preparation for Activity 5: Deck of cards

Each group will need to shear a stack of some sort of cards. These could be playing cards, index cards, old business cards, even older computer cards, but probably not baseball cards. Because students draw on the cards and measure angles, this is better done as an activity than as a demonstration (Fig. 5).

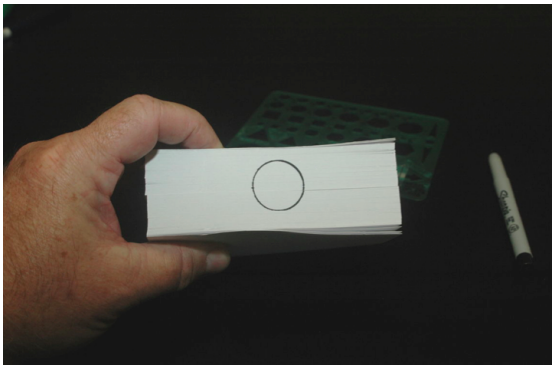

Figure 5. Deck of cards waiting to be sheared. Cronin, 2012.

Materials: For each group, a stack of cards; a circular stencil or object; a protractor; and black, blue, and red pens or pencils.

Sources:

All photos from these Instructor's notes and on the lab sheets, except for Activity 2, are Vince Cronin's, Baylor University, 2012.

Activity 2: Compressional springs

Lucarelli. 2009. Cavallini da gioco.
http://commons.wikimedia.org/wiki/File:Cavallini_da_gioco.JPG Retrieved from Wikimedia Commons 18 February 2013.

Model 1: Bungee cords Name(s):_____

Please complete this worksheet to understand quantitatively how the length of a bungee cord changes as you pull on its ends. You know what will happen, of course, but you've probably never measured the changes. Why bother? The measured change in length will teach you principles of strain in its simplest form—one-dimension.

Step 1. Assemble the apparatus.

Follow your teacher's instructions on setting the activity up if the model is different than the one shown below (Fig. 1.) Otherwise, pull the loose bungee end to the near hook and place the ruler with the zero-end at the leftmost of the two black threads. Tape the ruler to the board.

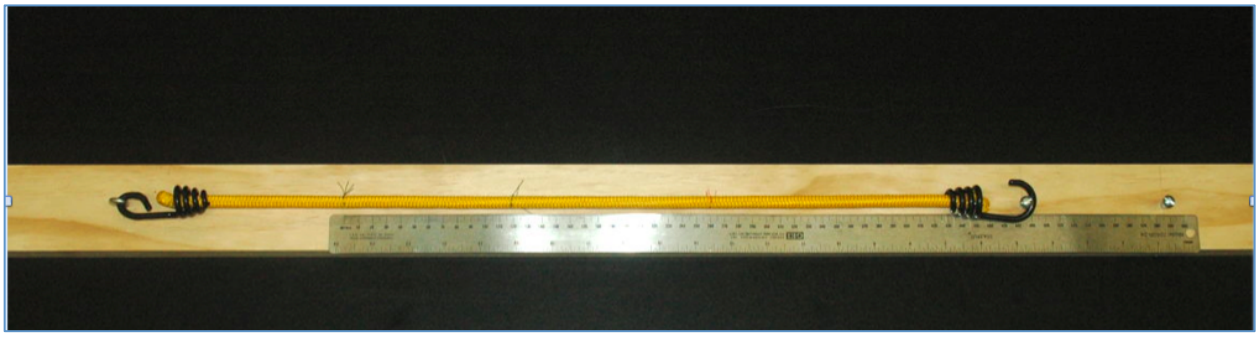

Figure 1. An example of the bungee cord apparatus. Note the position of the ruler with respect to the black thread on the left side. Cronin, 2012.

Step 2. Measure the original lengths—the initial state.

Follow your teacher's instructions regarding safety.

Distance to black thread ($l_{o\ black}$) = _____cm **Distance to red thread ($l_{o\ red}$) =**_____cm

Step 3. Stretch the bungee to the second hook and measure the final lengths.

Distance to black thread ($l_{f\ black}$) = _____cm **Distance to red thread ($l_{f\ red}$) =**_____cm

Step 4. Calculate the extension.

Calculate the extension measured to the black thread. l_o is the original length. l_f is the length after straining.

extension, *e*, is $\frac{l_f - l_o}{l_o}$ e_{black} =_____

Calculate the extension measured to the red thread.

extension, *e*, is $\frac{l_f - l_o}{l_o}$ e_{red} =_____

Step 5. Compare the extension.

Discuss how the extension measured using the black thread compares to that using the red one.

Step 6. Meet displacement vectors.

Geodesists measure changes in the shape of the crust with GPS units that can detect movement as little as a few millimeters per year. You can see and use this data from the UNAVCO's GPS Velocity Viewer. The data appears as an arrow in which the length of the arrow corresponds to the distance the station has moved, and the direction it points, obviously, shows the direction it's moved. It's a "displacement vector" (Fig. 2). (Search for "UNAVCO velocity.")

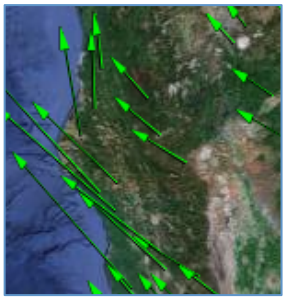

Figure 2. Displacement vectors for GPS stations in California.

In order to understand two-dimensional strain on Earth later, let's think about the bungee in terms of vectors. Think of the bungee in a coordinate system lying along the x-axis. Imagine the position of the black (or red) thread to be shown as a "location vector" which starts at the zero-mark of the ruler and goes along the x-axis to the thread. (Alternatively, you can think of the position as a coordinate along the x-axis.) The original position of the black thread was the distance $l_{o\ black}$ from the origin. As a vector, we'd call the same spot x_{bo} (*x* for the x-axis, *b* for black, and *o* for original).

a. Return the bungee's hook to the pin on the left. Slip a piece of paper under the bungee and mark it with the position of the black thread on one side of the bungee and the red thread on the other side.

b. Now extend the bungee (again) by hooking it to the pin on the right. On the paper, mark the new position of the black and red threads.

c. Draw arrows on the paper showing the change in position of both the black and red threads. These arrows are displacement vectors. Designate them u_{black} and $u_{red.}$

d. Measure the displacement vectors.

length u_{black} = _____ cm *length* u_{red} = _____ cm

e. Calculate extension again as the difference between the lengths of the displacement vectors divided by the difference between the lengths of the initial location vectors.

$$e = \frac{u_{red} - u_{black}}{x_{ro} - x_{bo}} = \frac{\Delta u}{\Delta x} =$$

(Δ is the symbol for "change in" in math and science.)

f. How does *e* measured in step 6e compare to *e* measured in step 4?

Model 2: Compressional springs Name(s):_____

Please complete this worksheet to understand quantitatively how the length of a compressional spring changes as you push the ends together. Recall a geologist's definition of extension, e, from your exploration of bungee cords.

Figure 7: **C**avallini da gioco. (Italian playground horses.) Photograph by Lucarelli. 2009.

Step 1 (Optional). Design your apparatus.

For your compressional spring, design a way to measure extension, *e*, under at least two conditions. Draw the design of your apparatus.

Describe the two conditions.

List materials you need.

Check your design and conditions with your instructor. Instructor's initials: _____

Step 2. Build and test your apparatus.

Follow your teacher's instructions regarding safety.

Step 3 (Optional). Redesign your apparatus.

Describe changes needed and why.

List new materials you need.

Step 4. If needed, rebuild and test your apparatus again.

Repeat until you are satisfied with the way your apparatus works.

Step 5. Measure extension.

Under the first set of conditions, measure the original length and the shortened length. Repeat three times. Record your data.

Trial 1: Original length: _____ cm Final length: _____ cm

Trial 2: Original length: _____ cm Final length: _____ cm

Trial 3: Original length: _____ cm Final length: _____ cm

Under the second set of conditions, measure the original length and the shortened length. Repeat three times. Record your data.

Trial 1: Original length: _____ cm Final length: _____ cm

Trial 2: Original length: _____ cm Final length: _____ cm

Trial 3: Original length: _____ cm Final length: _____ cm

Step 6. Calculate extension.

For both sets of conditions, calculate extension for each measurement (six total). Average for the first set and again for the second set.

Condition 1:

Trial 1 *e* =

Trial 2 *e* =

Trial 3 *e* =

Average *e* =

Condition 2:

Trial 1 *e* =

Trial 2 *e* =

Trial 3 *e* =

Average *e* =

Each of the arrows ("vectors") on this map show how a GPS station affixed to the ground is moving. The longer the arrow, the faster it is moving—in the direction the arrow points.

Based on the experiments you have done with bungee cords and compression springs, how do the different length vectors in the map relate to your experiment?

Which of the experiments in your class most closely matches what you are seeing in the Pacific Northwest?

Model 3: Tee shirts **Name(s):_____**

Please complete this worksheet to understand how deformation plays out in two dimensions. This will include moving a piece of tee shirt fabric as a whole and stretching it in various ways. Why? This introduces the changes in position and shape of a region of Earth's crust. The tee shirt will represent an area defined by three GPS stations, each of which could move over time.

Step 1. Gather your team and grab the shirt all around so that the fabric is taut and the circle is still round.

Move together in the same direction a few steps. This is "translation."

Step 2. Spin as a group.

Move together as a group, keeping the circle round. What would you call this?

Step 3. Start again with the tee shirt taut and with a round circle. All of you pull against each other.

Draw a before and after picture of the circle here:

Step 4. Imagine washing and drying the tee shirt in very hot water 50 times.

Draw a before and after picture of the circle here:

Step 5. Have a team member tug on the tee shirt while everyone else stays in place, with their elbows against their bodies.

Draw the inked shape here:

Step 6. Start again with the tee shirt taut and with a circle. Choose sides and have a gentle tug-of-war over the tee shirt.

Draw the inked shape here:

Model 4: Silly Putty® Name(s):_____

Please complete this worksheet to experience pure strain first-hand. Strain is the change in shape or volume of an object. Your task is to play with Silly Putty® and to see what happens to it over time.

Step 1. Prepare the Silly Putty®.

Roll your handful of Silly Putty® into a fat cylinder. Flatten the ends and one side. Push the open end of a vial or small bottle into the flat side so that the putty has an indented circle. Follow your teacher's instructions regarding safety.

Measure the diameter of the circle in centimeters. Diameter = _____ cm

Step 2. Wait and observe.

As you do some other task, watch the Silly Putty®. Note what you see happening. Write your observations.

Step 3. Finalize your observations.

Sketch what the entire cylinder looks like. Pay particular attention to the indented shape. Also, draw the indented shape at a scale of 1:1.

Measure the long axis of the indentation and an axis perpendicular to it.

Long axis = _____ cm Perpendicular axis = _____ cm

Step 4. Analyze your observations.

Discuss what caused the Silly Putty® to change shape and illustrate your response with a sketch. This style of deformation is due to pure strain.

Model 5: Cards

Name(s):_____

Please complete this worksheet to experience simple strain first-hand. Your task is to shear a stack of cards with a circle and to note carefully what happens to the shape of a circle drawn on the stack's side.

Step 1. Prepare the cards.

Draw a circle on the edge of a stack of cards to look like that below. (Fig. 1.)

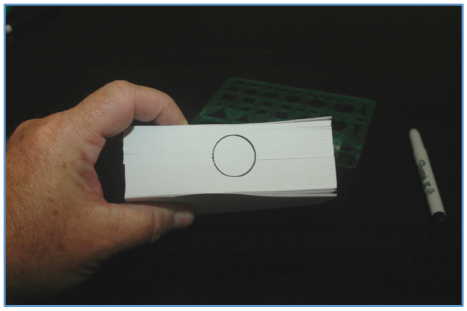

Figure 1. Deck of cards ready to shear. Cronin, 2012.

Step 2. Shear the cards.

Using a book or the table, push against the side of the stack so that each card moves a little to the left of the one below it. This is called "shearing," and the resulting change of shape is simple strain. (Fig. 2.)

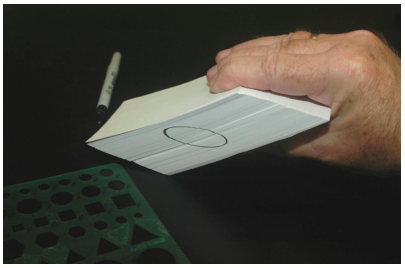

Figure 2. Deck of cards sheared against a table. Cronin, 2012.

Step 3. Draw and measure strain axes.

Use your red pen and a straight edge to draw an axis through the longest part of the ellipse showing on the side of the cards. This is the "major axis" of the strain ellipse. Use the blue pen to draw a shorter axis perpendicular to the red one. This one is the "minor axis" of the strain ellipse. (Fig. 3.)

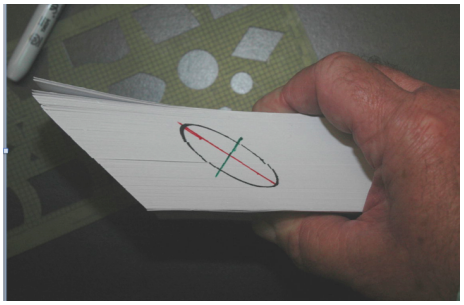

Figure 3. Strain axes drawn through the strain ellipse. Cronin, 2012.

Put the stack flat on the table and measure the angle between the major axis of the ellipse and the table.

Angle = _____ degrees

Step 4. Reverse the shear.

Restore the deck of cards to its original shape and so that the ellipse has reverted to a circle.

What is the angle between the major and minor axes?

Angle = _____ degrees

Again, put the stack on a table. What is the angle between the major axis and the table now? (Measure this.)

Angle = _____ degrees

How much did the major axis rotate from the sheared deck to the restored deck?

Rotation = _____ degrees

Now think of that rotation in reverse. From the initial state (or restored state), how much did the major axis rotate to its sheared state? Was the rotation clockwise or counterclockwise? This rotation is designated with an omega, Ω.

Ω = _____ degrees (Clockwise or counterclockwise?)

This particular style of strain—with rotation of strain axes—is called simple strain.