



# NASA eClips™

## Educator Guide

### ***NASA'S REAL WORLD***

#### *Self Healing Materials*



Educational Product

Educators & Students

Grades 6-8

NP-2009-12-232-LaRC

[www.nasa.gov](http://www.nasa.gov)

**National Standards:****National Science Education Standards  
(NSES)****Science as Inquiry**

Understanding about scientific inquiry

**Physical Science**

Properties and changes of properties in matter

**National Council of Teachers of Mathematics  
(NCTM)****Measurement**

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements.

**International Society for Technology in  
Education: National Educational Technology  
Standards (ISTE/NETS)****Digital Citizenship**

Exhibit a positive attitude toward using technology that supports collaboration, learning and productivity

**Lesson Overview:**

This lesson is developed using the 5E model of learning. Students look at NASA technology and how advanced materials are being developed and projected for use in many applications. They make a simple polymer, explore its properties, and investigate what effect changing the proportion of ingredients has on the properties of the polymer.

**Grade Level:**

6-8

**Subjects:**

Physical Science,  
Measurement, Ratios

**Teacher Preparation****Time:**

1 hour

**Lesson Duration:**

Two 55 minute class meetings.

**Time Management:**

Time can be reduced to one and a half periods if some of the questions are completed at home.



Icons flag four areas of interest or opportunities for teachers.

• **Technology Icon** highlights opportunities to use technology to enhance the lesson.



• **Modification Icon** denotes opportunities to differentiate the lesson.



• **Check for Understanding Icon** suggests quick, formative assessment opportunities.



• **Connections Icon** identifies opportunities to relate the lesson to historical references and other topics of discussion.

### **Materials List:**

#### Teacher Demonstration

- two latex balloons
- petroleum jelly
- wooden skewer

#### Explore (per group of 2)

- 2 paper cups
- aluminum pie pan
- metal spoon or heavy-duty wooden craft stick
- bowl
- measuring cup
- 2 plastic zipper bags
- 240 mL of cornstarch
- 240 mL of water (some groups will use less)
- Student Guide (1 per student)
- cornstarch and water recipe cards (1 per student)
- newspaper or other material to cover work surface
- damp paper towels
- hand sanitizer

#### Extend (per group of 3 students)

- 40 mL of white glue (some groups will use less)
- 50 mL graduated cylinder
- 40 mL of borax solution (directions for making solution are included in this guide)
- 5 mL of powdered borax
- two clear 360 mL plastic cups
- two plastic teaspoons
- black permanent marker
- 3 plastic zipper bags

- meter stick
- three large paper clips
- polymer recipe cards (1 per student)
- safety goggles
- newspaper or other material to cover work surface
- damp paper towels
- hand sanitizer

**Essential Questions:**

- How are a substance's properties affected by its composition?
- How do safety concerns drive the advancement of technology in exploration?

**Instructional Objectives:**

Students will:

- Measure the ingredients to make a polymer;
- Make a polymer and explore its properties;
- Investigate the effect of changing the ratio of ingredients on the properties of a polymer;
- Calculate the ratios of ingredients in different batches of polymer.

## 5E Inquiry Lesson Development

**ENGAGE (15 minutes)**

1. Blow up two standard round balloons to about 2/3 full.
2. Ask students to predict what will happen when you push against the balloon with the wooden skewer. Push the skewer into one of the balloons to pop it. Ask students why this happened. *(As the latex balloon is pierced, it pulls away from the point where it is pierced. Air rushes out of the space around the outside of the skewer and the latex can no longer withstand the air pressure inside the balloon.)*
3. Tell students that you will push the skewer through the balloon without popping it.
4. Coat the skewer in petroleum jelly. Insert the skewer into the end of the balloon opposite the knot with a gentle twisting motion. Continue to push the skewer through the balloon in this manner until you have pushed it out through the other side, close to the knot.

5. Observe what happens to the balloon. (*The balloon does not pop.*) Ask students why they think this happened. (*Latex is a polymer, a long chain of small molecules joined together. The lubricated skewer is able to slide in between the chains of the polymer without breaking the structure of the polymer.*)



6. **(TECHNOLOGY)** Show the NASA eClips™ video segment *Real World: Self Healing Materials* (6:08) to students at

<http://www.nasa.gov/audience/foreducators/nasaclips/search.html?terms=%22Self-Healing%20Materials%22&category=0100>



- (MODIFICATION)** The video may be streamed from either web site. The video may be downloaded from the nasa.gov web site; a captioned version is also available at the nasa.gov site. This video may be streamed from the NASA eClips™ YouTube channel:

[http://www.youtube.com/watch?v=HqW\\_g9EIBDY](http://www.youtube.com/watch?v=HqW_g9EIBDY)

7. Ask students to compare and contrast the self-healing polymer materials being developed by NASA to the balloon puncture demonstration

### EXPLORE (30 minutes)

There are three common states of matter: solid, liquid, and gas. Each of these states of matter has unique physical characteristics. Solids have a definite shape and volume. The atoms or molecules of the solid are packed tightly together. The units in a solid vibrate in place. Liquids have a definite volume but no definite shape. The atoms or molecules in a liquid are closely packed but have enough room to move past each other. Gases have no definite shape or volume. Because of the relatively high energy level that gas molecules have, the individual atoms or molecules are not as strongly attracted to other molecules as they are in a solid or liquid. The gas molecules break apart from each other and are free to move in all directions.

Although most materials can be classified into one of these three states, there are exceptions. One exception is a class of substances called non-Newtonian fluids. These substances act like liquids when no force is applied to them and act like a solid when a force is applied. Many non-Newtonian fluids are solutions of polymers. Polymers consist of repeated small units linked together in long chains. The small units are small molecules called monomers.

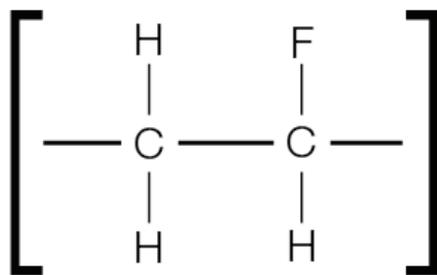


Figure 1. A monomer

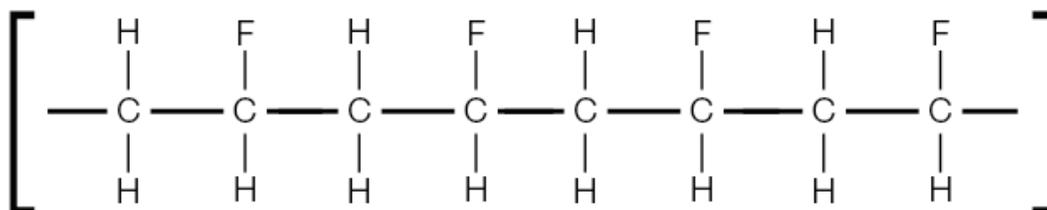


Figure 2. A polymer.

The polymer illustrated above is polyvinylidene fluoride, or PVDF. In figures 1 and 2 above, C represents a carbon atom, H represents a hydrogen atom, and F represents a fluorine atom. The line segments between the atoms represent covalent bonds that hold the atoms together.

In this activity, students will make a non-Newtonian fluid using cornstarch and water. Cornstarch is an organic polymer made up of long chains of glucose molecules joined together. The organic polymer in cornstarch is also called amylose.

1. Before class, reproduce the sets of cornstarch and water recipe cards on page 10. Cut apart the recipes and mount them on cardstock. Laminate the cards for durability. Each group will need two copies of the recipe they will be making.
2. Organize students in teams of two.
3. Distribute the Student Guide. Give Cornstarch Recipe A to half of the groups in class and Cornstarch Recipe B to the other half of the class.
4. Once the students have made the fluid, direct them to explore the properties of the mixture as outlined in the Student Guide on page 4, step 8 and record their observations in Table 1 on page 5 of the Student Guide.

5. Once they have finished, have each team label two cups with the letter of the recipe they made. They should then pour half of the mixture into one cup and the other half of the mixture into the second cup. Each student should keep one cup.



6. **(MODIFICATION)** To make this activity more open-ended, allow students to choose their own ratio of cornstarch to water. Note that students will not observe the solid-like properties of the mixture if the ratio of cornstarch to water is less than 1.5 to 1. Likewise, liquid properties will not be observed if the ratio of cornstarch to water is greater than 2.5 to 1.



7. **(MODIFICATION)(TECHNOLOGY)** If students do not understand the concept of ratios, show the NASA eClips™ video segment, *Real World: Scale Models and Ratios*. The video may be found at:



<http://www.nasa.gov/audience/foreducators/nasaclips/search.html?terms=%22Scale%20Models%20and%20Ratios%22&category=0100>

or

<http://www.youtube.com/watch?v=IYizhPvMWQ&feature=Playlist&p=887C1C3BAAD53F17&index=36>

### EXPLAIN (15 minutes)

1. Regroup the students in pairs so that each group has one student with a Cornstarch Recipe A mixture and the other student has a Cornstarch Recipe B mixture.
2. Have students share both their data and recipe. Encourage them to explore the properties of the other student's mixture.



3. **(MODIFICATION)** If students were allowed to choose their own ratios of cornstarch to water in the EXPLORE activity, have them post their recipe and observations on the board.



4. **(CHECK FOR UNDERSTANDING)** Have students share their observations with the class. Ask the students to give their opinion as to which mixture is better. Students should list their criteria for what makes one mixture better than the other and defend their choice with data collected in class. Lead them to understand that the final use of the mixture determines which mixture is better.

**EXTEND (55 minutes)**

Students can test a different polymer solution made from white glue and a borax solution.

1. Before class, make a saturated borax solution. (Borax is available in the laundry detergent aisle of a grocery store.) Fill a container with 1 liter of water. Slowly add borax powder to the water while stirring until no more powder will dissolve.

*SAFETY NOTE: Borax is toxic if ingested in large quantities. Be sure to follow the precautions listed on the side of the box. Remind students that they should never taste anything in a lab and that they should wash their hands when they are finished. Students should wear safety goggles during this activity.*

2. Reproduce the sets of polymer recipe cards on page 10. Cut apart the recipes and mount them on cardstock. Laminate the cards for durability. Each group will need three copies of the recipe they will be making.
3. Divide the class into groups of three. Assign one-third of the groups to make each of Borax Recipes “A”, “B”, and “C”. Each student in the group should have a recipe card.
4. Demonstrate the procedure given in the Student Guide for marking the plastic cups at 20 mL, 30 mL and 40 mL using a graduated cylinder and water. Emphasize that the cup should be emptied prior to mixing the polymer solution.



**(MODIFICATION)** To save time the teacher can mark the cups in advance.

5. In step 10 of the procedure, students are directed to add a teaspoon of powdered borax to the borax solution. This is done to ensure that the solution is saturated and that a polymer will form.
6. Students record observations about the polymer they made, and then put one-third of the mixture in each of three different plastic bags. Using a permanent marker, students should mark an A, B, or C on the outside of the bag to identify which recipe they made.
7. Regroup the students so that each of the new student groups has three different recipes. Have students share both their data and recipes.

**EVALUATE (15 minutes)**

1. Use questions, discussions, and work in the Student Guide to assess students' understanding.
2. Ask students to summarize their learning by answering the following journal questions:
  - a. Why is it important to measure substances accurately when following the directions to make a product? *(If the measurements are not accurate then the product may not have the desired properties.)*
  - b. How does what you created in lab compare to what NASA researchers are doing? *(In both cases, several different ratios of ingredients are tested to see how they perform. NASA researchers conduct many more trials and use many more combinations of materials than were used in class.)*
  - c. How do safety considerations drive the advancement of technology in exploration? *(Researchers are developing safer materials by modifying the composition of existing materials to enhance desired safety traits.)*
  - d. **(CONNECTIONS)** What are some other uses for self-healing materials? *(Answers will vary but may include using them for making space suits, for the outside of automobiles or for clothing.)*



**RECIPE CARDS**

**Cornstarch and Water  
Recipe Cards**

**Cornstarch Recipe A**

240 mL of cornstarch  
120 mL cup of water

**Cornstarch Recipe B**

240 mL of cornstarch  
145 mL cup of water

**Polymer  
Recipe Cards**

**Borax Recipe A**

20 mL glue  
20 mL of water  
40 mL of borax solution

**Borax Recipe B**

30 mL of glue  
10 mL of water  
40 mL of borax solution

**Borax Recipe C**

40 mL of glue  
0 mL of water  
40 mL of borax solution

## Essential Questions

- How are a substance's properties affected by its composition?
- How do safety concerns drive the advancement of technology in exploration?

## Background

As human beings travel farther into space, NASA needs new, advanced materials to design and build the spacecraft that will travel to faraway worlds. Astronauts will not find any parts stores or repair shops millions of kilometers from Earth. Damage caused to a spacecraft from fast-moving debris in space, such as comets or pieces of meteoroids, could be fatal. A spacecraft must be made of strong material that can repair itself.

Stress on current composite material tends to form tiny hairline cracks that cause major damage over time. Scientists observing the human body noticed that the body has an amazing ability to heal itself. When skin gets cut, the body works to pull the skin around the cut back together. Scientists are now developing a new type of **composite material** that will mimic self-healing properties. This new material reacts to objects that pierce it by closing the gap behind the object. Different **monomers** are combined to form a **polymer** with the unique ability to snap back after a puncture. This new material is not only self-healing, it is very strong. NASA researchers believe this material and other polymers like it will help overcome the biggest dangers of air and space travel.

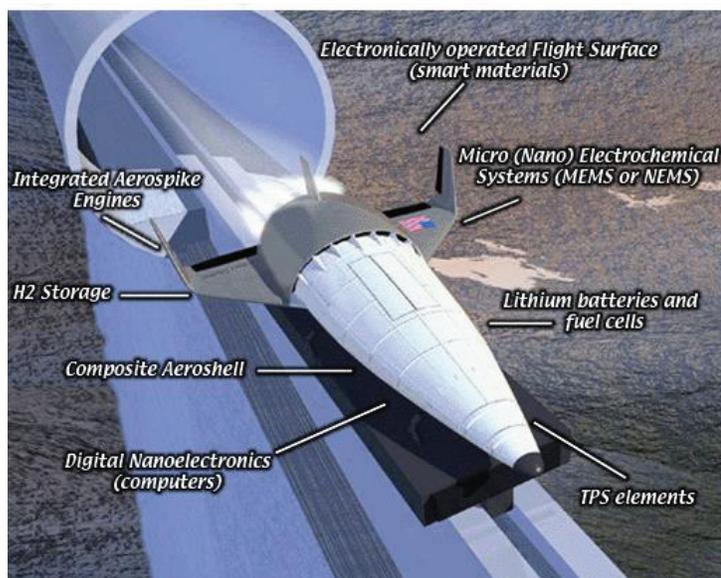


Figure 1. Advanced materials will be essential for making dramatically improved spacecraft possible.

Image Credit: NASA

## Spacecraft Skins

However NASA researchers are hoping to add even more improvements to these new **self-healing materials**. Skin contains millions of microscopic nerves and nerve endings to carry signals to the brain. These nerves allow humans to feel the slightest pinprick anywhere on the body. In many cases, this self-monitoring allows a person to react to the warning and avoid serious injury. On long-term spaceflights, materials that had similar abilities to self-monitor would be beneficial. Materials that make-up critical systems in a spaceship could be embedded with very tiny, or nanometer-scale sensors that constantly monitor the materials' condition. If some part begins to fail, sensors could alert the central computer before major damage occurs. These self-healing and self-monitoring materials could also have practical uses for consumers in the future.



**Figure 2.** This piezoelectric material, developed at NASA's Langley Research Center (LaRC), can "feel" deformations such as bending or surface pressure, producing a small voltage in response that can act as a signal for a central computer.

Image Credit: NASA

### Resources:

NASA Web site

[http://science.nasa.gov/headlines/y2002/16sep\\_rightstuff.htm](http://science.nasa.gov/headlines/y2002/16sep_rightstuff.htm)

For more information on self healing materials, visit

[http://science.nasa.gov/headlines/y2001/ast01mar\\_1.htm](http://science.nasa.gov/headlines/y2001/ast01mar_1.htm)

**Vocabulary**

**atom** – Atoms are the smallest part of an element that maintains the chemical properties of that element.

**composite materials** – Composite materials are two or more different materials that are combined together. The combined materials do not lose their individual properties. The properties of the product are a combination of the properties of each material.

**covalent bond** – A covalent bond is a chemical bond formed between two atoms by sharing electrons between the atoms.

**fluid** – A fluid is a substance that will flow. When a substance flows, the particles in the fluid can move past one another. Both liquids and gases are fluids.

**mixture** – A mixture is a physical combination of two or more substances. Each substance in a mixture retains its own physical and chemical properties.

**molecule** – A molecule is a group of two or more atoms held together by a covalent bond.

**monomer** – A monomer is a small molecule that is linked with large numbers of other small molecules to form a chain or a network (polymer).

**Newtonian fluid** – A Newtonian fluid is a fluid that reacts the same way no matter how much stress, or force, is applied to it.

**non-Newtonian fluid** – A non-Newtonian fluid is a fluid that changes behavior depending on the amount of stress, or force, applied to it.

**polymer** – A polymer is long or large molecule consisting of a chain or network formed by chemically bonding many repeating units, or monomers, together.

**saturated solution** – A saturated solution contains the maximum amount of solute that can be dissolved in a given amount of solvent at a specified temperature.

**self-healing material** – Self-healing materials are able to repair damage by closing the gap around a penetrating object.

**solute** – The solute is the dissolved component of a solution. The solute is usually, but not always, present in a smaller amount than the solvent.

**solution** – A solution is a homogeneous mixture of two or more substances. The composition of a solution is the same throughout.

**solvent** – The solvent is the component of a solution that dissolves one or more solutes.

## EXPLORE

### Materials

- 2 paper cups
- aluminum pie pan
- metal spoon or heavy-duty wooden craft sticks
- bowl
- measuring cup
- 2 plastic zipper bags
- safety goggles
- newspaper or other material to cover work area
- damp paper towels
- hand sanitizer

1. Cover your work area with newspaper or other material to protect the surface from spills.
2. Your teacher will give you a recipe card with the amounts of each ingredient you will use.
3. Put on your safety goggles.
4. Measure the cornstarch and pour it into the bowl.
5. Slowly add the water to the cornstarch while stirring carefully. The mixture may become hard to stir.
6. Continue stirring until no more powder is visible.
7. Pour the mixture into the aluminum pie pan.

***SAFETY NOTE:*** *Never taste anything in a lab, even if you think you know what it is. Be sure to wear your safety goggles.*

8. Investigate the properties of the mixture by doing the following actions. Record your observations in Table 1.
  - a. Quickly poke your finger into the mixture.
  - b. Lay your finger on the surface of the mixture.

- c. Pick up some of the mixture and hold it in the open palm of your hand.
  - d. Pick up some of the mixture and squeeze it tightly.
  - e. Set a spoon on the surface of the mixture.
  - f. Stir the mixture with the spoon.
  - g. Push on the mixture in the aluminum pie pan with your hand. Record what happens when you push with your hand and when you pull your hand out.
9. Label the two plastic bags with the letter of the recipe you made. Divide your mixture in half and place each half in a separate plastic bag. Be sure to close the bag tightly. Each person in the group should keep one of the bags.
  10. Throw away the table covering and wipe up the area with damp paper towels and use hand sanitizer to clean your hands.

**Table 1. Observations of Cornstarch Mixture****Cornstarch Recipe A      Cornstarch Recipe B (circle one)**

Action	Observations
Observing with touch and sight	
Quickly poking finger into mixture	
Laying finger on surface	
Holding mixture in open palm	
Squeezing mixture tightly	
Setting spoon on surface	
Stirring mixture	
Pushing mixture with hand	
Removing hand	

**EXPLAIN**

1. Once your teacher has placed you in a new group, talk with your new partner and fill in Table 2.

**Table 2. Observations of Another Group's Cornstarch Mixture****Cornstarch Recipe A      Cornstarch Recipe B (circle one)**

Action	Observations
Observing with touch and sight	
Quickly poking finger into mixture	
Laying finger on surface	
Holding mixture in open palm	
Squeezing mixture tightly	
Setting spoon on surface	
Stirring mixture	
Pushing mixture with hand	
Removing hand	

Use the information you have learned in this activity to answer the following questions:

1. What are the properties of a solid?
2. What are the properties of a liquid?

3. What happened when you applied pressure to the cornstarch mixture?
4. For Cornstarch Recipe A, does the mixture act more like a solid or a liquid? Support your answer with observations from Tables 1 and 2.
5. For Cornstarch Recipe B, does the mixture act more like a solid or a liquid? Support your answer with observations from Tables 1 and 2.
6. Look at the recipe cards for Cornstarch Recipes A and B. What is the ratio of cornstarch to water in Cornstarch Recipe A?
7. What is the ratio of cornstarch to water in Cornstarch Recipe B?
8. What effect did changing the ratio of cornstarch to water have on the properties of the mixture? Support your answer with observations from Tables 1 and 2.
9. Does the statement “The ratio of cornstarch to water in this mixture is 3 to 1” mean thing the same as the statement “The ratio of water to cornstarch is 3 to 1?” Explain your answer.

## EXTEND

### Materials

- 40 mL of white glue (some groups will use less)
- 50 mL graduated cylinder
- 40 mL of borax **solution** (directions for making solution are included in this guide)
- 5 mL tsp of powdered borax
- two clear 360 mL plastic cups
- two plastic teaspoons
- black permanent marker
- 3 plastic zipper bags
- paper towels
- meter stick
- three large paper clips
- safety goggles
- newspaper or other material to cover work surface
- damp paper towels
- hand sanitizer

1. Cover your work area with newspaper or other material to protect the surface.
2. Put on safety goggles.
3. Measure 20 mL of water in a graduated cylinder. Pour the water into one of the plastic cups.
4. Use the permanent marker to mark the level of the water in the cup. Write “20 mL” next to the mark. Empty the cup.
5. Measure 30 mL of water. Pour this water into the cup you just marked. Mark the new water level and write “30 mL” next to it.
6. Repeat step 3 with 40 mL of water. Empty the cup.
7. Use the permanent marker to label one of the plastic spoons “glue” and the other “borax.”
8. Your teacher will assign you a recipe to make. Use the plastic cup you have marked to measure the glue required for your recipe. Leave the glue in the cup.

9. Use the graduated cylinder to measure the amount of water you need. Pour this water into the plastic cup with the glue. Mix the two ingredients thoroughly with the spoon marked “glue.”
10. Use a dry graduated cylinder to measure 40 mL of borax solution. Pour this solution into the empty cup. Using the spoon labeled “borax”, add one spoonful of powdered borax to the solution and stir well. The solution is saturated so the powder should not dissolve. If the powder dissolves completely, ask your teacher to check your work. You may need to add more borax to the solution to make sure it is saturated.
11. Make some observations about each solution. Record your observations in Table 3.  
  
**SAFETY NOTE:** *Never taste anything in a lab setting even if you think you know what the substance is.*
12. While one group member stirs the glue solution, another group member should slowly pour the borax solution into the cup with the glue solution. Observe what happens in this process and record your observations in Table 3.
13. Scoop the polymer out with the spoon and set it on the work surface. Rinse out both cups.
14. Remove the polymer from the spoon and gently squeeze it with your hands until all of the excess water has been removed.
15. Use sight and touch to make observations about the polymer. Record your observations in Table 3.
16. You will now test your polymer. Perform each of the tests below and record your results in Table 4 in the column matching your recipe.
  - a. Set the end of the meter stick on the floor. Hold the polymer at a height of 100 cm and drop it.
  - b. Try to roll the polymer into a ball.

- c. Use the large paper clips to make imprints on the polymer. Time how long it takes until the imprint begins to disappear.
  - d. Roll the polymer into a 10 cm rope. While one group member holds the meter stick, the other two group members should pull on the ends of the rope. Record how long the polymer stretches before it breaks.
17. Once all tests have been completed, divide the polymer into thirds. Put each piece in a separate plastic bag and label the bag with the letter of the recipe you made. Each group member should keep one bag.
  18. Throw away the table covering and wipe up the area with damp paper towels.
  19. Use hand sanitizer to clean your hands.
  20. After your teacher has assigned you to a new group, share your test results with your group members and answer the questions.

**Table 3. Observations of Solutions and Polymer**

	Observations
Glue Solution	
Borax Solution	
Mixing of Solutions	
Polymer	

**Table 4. Test Results**

Test	Borax Recipe A	Borax Recipe B	Borax Recipe C
Drop Test			
Ball Test			
Imprint Test			
Stretch Test			

**Student Questions**

1. Compare the glue solution to the borax solution. How are they the same?  
How are they different?
2. What happened when you mixed the glue and borax solutions?
3. For each of the recipes, calculate the ratio of glue to borax solution.
4. As a group, decide on a use for this polymer. Determine which recipe is the best for making this polymer based on the use you have selected. Support your choice with data collected in the lab.
5. *OPTIONAL*: Name the polymer based on the characteristics you have observed.

**Answer Key****Table 1. Observations of Cornstarch Mixture****Cornstarch Recipe A      Cornstarch Recipe B (circle one)***Answers will vary. Examples given below are for Recipe A*

<b>Action</b>	<b>Observations</b>
Observing with touch and sight	<i>Smooth, hard, looks like clay</i>
Quickly poking finger into mixture	<i>Hard to poke, indentation fills in quickly</i>
Laying finger on surface	<i>Turns runny, finger sinks, hard to pull finger out</i>
Holding mixture in open palm	<i>Feels cold, spreads out, sticks to hand</i>
Squeezing mixture tightly	<i>Turns solid, feels powdery</i>
Setting spoon on surface	<i>Spoon sinks a little bit</i>
Stirring mixture	<i>Hard to stir, turns into chunks</i>
Pushing mixture with hand	<i>Feels solid when pressed, cracks form</i>
Removing hand	<i>Handprint and cracks fill in</i>

**EXPLAIN****Table 2. Observations of Another Group's Cornstarch Mixture****Cornstarch Recipe A      Cornstarch Recipe B (circle one)***Answers will vary. Examples given below are for Recipe B*

<b>Action</b>	<b>Observations</b>
Observing with touch and sight	<i>Sticky, flows, looks like milk</i>
Quickly poking finger into mixture	<i>Ripples form, finger doesn't go all the way to the bottom</i>
Laying finger on surface	<i>Finger sinks quickly</i>
Holding mixture in open palm	<i>Oozes out of hand, flows like glue</i>
Squeezing mixture tightly	<i>Some oozes out, some feels solid</i>
Setting spoon on surface	<i>Spoon sinks into mixture</i>
Stirring mixture	<i>Hard to stir, chunks form and dissolve quickly, mixture fills in behind the spoon</i>
Pushing mixture with hand	<i>Hand sinks, feels solid under hand</i>
Removing hand	<i>Hard to remove, hand print fills in quickly</i>

**Student Questions:**

Use the information you have learned in this activity to answer the following questions:

1. What are the properties of a solid?

*Solids have a definite shape and volume, the structural units of the solid (atoms or molecules) are packed tightly together, and the units vibrate in place.*

2. What are the properties of a liquid?

*Liquids have a definite volume but no definite shape and the structural units are closely packed but have enough room to move past each other.*

3. What happened when you applied pressure to the mixture?

*When pressure is applied the mixture becomes stiffer (more like a solid)*

4. For Cornstarch Recipe A, does the mixture act more like a solid or a liquid? Support your answer with observations from Tables 1 and 2.

*Answers will vary but in general it acts more like a solid.*

5. For Cornstarch Recipe B, does the mixture act more like a solid or a liquid? Support your answer with observations from Tables 1 and 2.

*Answers will vary but in general it acts more like a liquid.*

6. What is the ratio of cornstarch to water in Cornstarch Recipe A?

*Recipe A:  $240/120 = 2$ , which is a 2:1 ratio.*

7. What is the ratio of cornstarch to water in Cornstarch Recipe B?

*Recipe B:  $240/145$  approximately equals 1.7, which is a 1.7:1 or approximately a 5:3 ratio.*

8. What effect did changing the ratio of cornstarch to water have on the properties of the mixture? Support your answer with observations from Tables 1 and 2.

*When the ratio of cornstarch to water decreases, the mixture becomes more like a liquid. Observations will vary.*

9. Does the statement “The ratio of cornstarch to water in this mixture is 3 to 1” mean thing the same as the statement “The ratio of water to cornstarch is 3 to 1?” Explain your answer.

*No. If the ratio of cornstarch to water is 3:1 then there is three times as much cornstarch as water which means the mixture would be very stiff. If the ratio of water to cornstarch is 3:1 then there is three times as much water as cornstarch and the mixture would be watery.*

**EXTEND****Table 3. Observations of Solutions and Polymer**

Answers will vary. Example observations are listed below.

	Observations
Glue Solution	A – Looks like milk, no texture, watery B – Looks creamy, has some air bubbles C – Thick liquid, white
Borax Solution	Cloudy water with solid on bottom
Mixing of Solutions	Becomes stringy, then clumps together Recipe A flows easily, B flows slowly, C becomes more solid
Polymer	A – Sticky, looks like slime B – Looks like a cooked egg white, a little sticky C – Feels rubbery, keeps the texture of hands

**Table 4. Test Results**

Answers will vary. Sample results are listed below.

Test	Borax Recipe A	Borax Recipe B	Borax Recipe C
Drop Test	Hits floor and splats	Bounced about 5 cm	Bounced about 30 cm
Ball Test	Can roll into ball but does not hold shape	Rolls into ball. Holds shape for a little bit	Easily rolls into a ball
Imprint Test	Cannot make an imprint	Paper clips sink About 20 seconds before imprint starts fading	About 30 seconds before imprint starts fading
Stretch Test	49 cm	33 cm	29 cm

1. Compare the glue solution to the borax solution. How are they the same?  
How are they different?

*Answers will vary. They are the same because they are both liquids. The glue solution is white, the borax solution is clear.*

2. What happened when you mixed the glue and borax solutions?

*As the two solutions were mixed, the polymer begins to form. It looks “stringy” at first.*

3. For each of the recipes, calculate the ratio of glue to borax solution.

*Recipe A:  $20/40 = \frac{1}{2}$  which means the ratio is 1:2*

*Recipe B:  $30/40 = \frac{3}{4}$  which means the ratio is 3:4*

*Recipe C:  $40/40 = 1$  which means the ratio is 1:1*

4. As a group, decide on a use for this polymer. Determine which recipe is the best for making this polymer based on the use you have selected. Support your choice with data collected in the lab.

*Answers will vary. For example, if students decided to use it as a super ball, they could point out that Recipe C is the best because it holds its shape the best and bounces the highest.*

5. **OPTIONAL:** Name the polymer based on the characteristics you have observed.