



**Designer Sneakers:
Teacher Pages
Short Version**

**Written By Three Polymer Ambassadors
For The Akron Global Polymer Academy**



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Table of Contents

	Page
What is a polymer?	3
Introduction	4
National Science Education Standards	5
ITEA Standards	6
Flow Chart of the 5 E's of the Learning Cycle	7
Unit Goals	7
Classroom Management	8
Materials List	9
Teacher notes on Engagement	10
Safety Notes	11
Teacher notes on Exploration.....	12
Rubrics for Exploration and Explanation	19
What is Compounding?	22
Integration with History.....	24
Teacher notes on Elaboration	24
Scoring Rubrics for Final Evaluation.....	26
Bibliography	28

Preface

Designer Sneakers: Short Version is written for upper elementary or middle school students (grades 5-9). This module will take 8-9 class periods to complete. The culminating activity is not a hands-on experience. The final evaluation is a written report about the creation of a designer sneaker based on their testing results. It is suggested that this module be used after the *Hands On Plastics Kit* has been introduced to the students. This kit is available free from the American Plastics Council at www.handsonplastics.com. The kit introduces students to the six recycled plastics and helps them learn to identify the plastics using physical and chemical properties. Revision of this popular kit was made in 2003.

What is a polymer?

Many teachers have heard about polymers and plastics but do not feel comfortable teaching about them or using them. Since polymers are found everywhere and you can't live without them, it is time to learn what a polymer is so in just a few short paragraphs the authors will give you a quick lesson! Polymers or macromolecules are found in the human body, animals, plants, minerals and manufactured products. Substances like the following contain polymers: diamond, concrete, quartz, glass, nylon, plastics, DNA, tires, cotton, hair, bread, and paint. A polymer is a large molecule consisting of a chain of low-molecular-weight units. These units are called monomers. The macromolecule can have different end units, branches in the chain, variations in the sequence of the monomers, and different monomers repeated in the same chain which leads to the large number of manufactured polymers as well as all of the natural polymers.

Polymer	Repeating Units	Monomer
Polyethylene	$\text{---CH}_2\text{---CH}_2\text{---}$	$\text{CH}_2=\text{CH}_2$
Poly(vinyl chloride)	$\text{---CH}_2\text{---}\underset{\text{Cl}}{\text{CH}}\text{---}$	$\text{CH}_2=\underset{\text{Cl}}{\text{CH}}$
Polypropylene	$\text{---CH}_2\text{---}\underset{\text{CH}_3}{\text{CH}}\text{---}$	$\text{CH}_2=\underset{\text{CH}_3}{\text{CH}}$
Polyacrylonitrile	$\text{---CH}_2\text{---}\underset{\text{CN}}{\text{CH}}\text{---}$	$\text{CH}_2=\underset{\text{CN}}{\text{CH}}$
Polystyrene	$\text{---CH}_2\text{---}\underset{\text{C}_6\text{H}_5}{\text{CH}}\text{---}$	$\text{CH}_2=\underset{\text{C}_6\text{H}_5}{\text{CH}}$

Natural polymers are in living animals and plants as building materials, storage substances and playing a role in biochemical reactions. Cellulose and lignin give structure to plants. Cellulose (starch or polysaccharide) is a macromolecule and a colloid composed on individual sugar molecules (glucose) that are bonded together to give molecular weights in the millions. Cellulose is the basis for cotton and rayon fibers. Starch is another colloid of plants that stores glucose and, therefore, energy. Starch resembles cellulose in that its monomer is glucose but it has a branched-chain structure rather than a straight chain. Chitin is a nitrogen-containing polysaccharide found in shells, wings, and claws of animals. Proteins are polymers that are responsible for animal hair and fibers such as wool and silk. DNA is a polymer necessary for life processes in plants and animals. Natural rubber, from a tree, has butadiene as the monomer producing a very elastic product. Artificial rubber also contains butadiene monomers but with additives to change the physical properties for the manufacture of automobile tires. Inorganic polymers (not based on the carbon atom) include glass with its silicon-oxygen framework and other silicates as in granite and agate.

Synthetic polymers or manufactured ones grew to importance from the work of Leo Baekeland in 1909. He worked with a viscous product made from the reaction of phenol with formaldehyde called Bakelite. He discovered that many useful plastics could be prepared by varying the proportions of the components and the conditions of the reactions. The chemical industry has produced a wide variety of products including fibers, plastics, synthetic rubber, coatings and adhesives from this initial work.

Introduction

This module will take eight to nine days if it is done with all the testing suggested. Feel free to reduce the time by using only one recipe for the compounding or choose only a few of the testing procedures. The final evaluation takes about two days since students draft their ideas and do not actually make the prototypes. Making the prototypes with designer insoles and midsoles is the best method to complete this unit but it takes more classroom time. The “Long Version” for the module has instructions for the prototypes. The objectives of the module are to address many of the National Science Education Standards and International Technology Education Association Standards. Students work cooperatively, are aware of the parts of an athletic shoe, learn how the various parts function to give comfort and support to the foot, and the importance of polymer compounding in achieving the physical properties needed for the insole and midsole of an athletic shoe. Using science and technology students make the best possible product. They experiment with additives to their basic recipe just as industry searches for the best properties for their shoe construction. Research on additives is an important component of the polymer industry and it is a vital part of the *Designer Sneaker*.

The introduction of community resource people enhances interest and knowledge of athletic shoes. Having a local shoe storeowner come into the classroom to show the latest styles and variety of athletic shoes creates more interest in this polymer project. Students are able to glean ideas about how they would like to design their shoes and also learn about business practices for selling shoes. Another popular resource is to ask high

school athletes to comment on their sports and the kind of athletic shoes needed for running, baseball, etc. The sequence of having the class test various polymers, meeting the resource people, forming their companies, and designing their final product seems to work well with this age student.

National Science Education Standards addressed:

Science Teaching Standards:

- A: Plan an inquiry-based science program
- B: Guide and facilitate learning
- C: Engage in assessment of student learning
- D: Design and manage learning environments
- E: Develop communities of science learners

Assessment of Science Education:

- A: Consistent with the decisions they are designed to inform
- B: Achievement and opportunity to learn science
- C: Technical quality of the data collected matches interpretation
- D: Fair
- E: Sound inferences from assessments

Science Content Standards for 5-8

A: Unifying Concepts and Processing

1. Systems, order, and organization
2. Evidence, models, and explanation
3. Consistency, change and measurement
4. Form and function

B: Science as Inquiry

1. Identify questions that can be answered through scientific investigations
2. Use appropriate tools and techniques to gather, analyze, and interpret data.
3. Think critically and logically to make the relationships between evidence and explanations.
4. Communicate scientific procedures and explanations.

C: Physical Science:

1. Properties and changes of properties in matter
2. Transfer of energy

D: Science and Technology:

1. Abilities of technological design
 - a. Identify appropriate problems for technological design.
 - b. Design a solution or a product.
 - c. Evaluate complete technological designs or products.
 - d. Communicate the process of technological design.
2. Understanding about science and technology

E: Science in Personal and Social Perspectives

1. Natural resources
2. Science and technology in society

F: History and Nature of Science:

1. Science as a human endeavor
2. Nature of science
3. History of science

Standards for Technological Literacy addressed (from ITEA):

The Nature of Technology

Standard 1. Students will develop an understanding of the characteristics and scope of technology.

Standard 3. Students will develop an understanding of the relationships among technologies and the connections between technology and other fields.

Design

Standard 8. Students will develop an understanding of the attributes of design.

Standard 10. Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

Abilities for a Technological World

Standard 11. Students will develop the abilities to apply the design process.

Standard 13. Students will develop the abilities to assess the impact of products and systems.

The module has an introduction about feet and shoes, the history of the athletic shoe, chemical compounding, and a learning cycle of activities. The **engagement** part of the learning cycle introduces students to the parts of a shoe and they are given the opportunity to dissect old shoes. The **exploration** of the learning cycle introduces compounding and testing with glue putties and latex. The **explanation** includes background reading on the parts of a shoe as students answer questions about their testing data. They are looking for patterns. There is a mini-**evaluation** after the testing. The **elaboration** requires teams of students to form a company to design newly compounded polymers for the insole and midsole of an athletic shoe. This is an assessment of their decision-making and using appropriate conclusions from their tests. The final **evaluation** is a written report about a newly designed athletic shoe. A scoring rubric is available for the report. A short reading on “Buying Shoes” is included.

Classroom Management Suggestions:

- Have students work in groups for four, with varying abilities, so that the factory team will be well balanced. The team will need an artist, a person who likes to test and record data, another person who likes to use Excel to make graphs or hand graphs, and a team member who will take consumer polls for opinions.
- Using pump-type nozzles for distribution of the diluted glue really minimizes clean up and waste.
- One area of the room should be designated for the glue dispensing station.
- Buckets of water located around the room will enable students to rinse their hands and keep the glue out of the sink drains.
- All materials for the five tests must be available from the beginning. Students should be able to work on any one test during each class period.
- Do not allow any glue putties to leave the classroom so no student is allowed to take any home. Discard used putties into the trash. They become moldy and dirty after days of use.
- Cover tabletops with newspaper and have aprons for students when doing the latex activity. Latex is not water soluble so do not wash hands! Just rub off any extra latex on hands into the trash. Throw away the cups and spoons, do not try to wash them.

Materials List for 32 students

50-50 glue mixture	2 liters
75-25 glue mixture	2 liters
2 liter dispenser bottles	2
pump dispensers to fit 2 L bottles	2
Talc	200 grams
Calcium carbonate	100 grams
Vegetable oil	200 mL
Food coloring	one set
Sodium tetraborate	60 grams in 1500 mL water
3 oz plastic cups (5 cups per team)	40 cups
sandwich bags	120 bags
permanent magic markers	8
craft sticks	40
10 ml grad. cylinder	8
balance is optional	
aprons are optional	
meter stick	8
15 cm ruler	8
yogurt cups	80
1 inch marble	8
PVC 1.25 ID tube 30 cm long	8
PVC 1.25 ID tube 60 cm long	8
Ring stand and clamp for PVC tube	8
Clear plastic wrap	1 box
Hex Bolts – ½ inch x 3 inches	8
Latex	200 mL
Vinegar	1 qt
Small spray bottles	8
Spoons	8
Scissors	8
T shirt fabric for latex	
Teaspoon measuring spoon	8
2 liter soda bottle top for demo	

Engagement

Teacher Notes: Answers to Study Guide (Homework Assignment)

1. The foot strikes the ground 70,000 times per week.
2. The three energy-storing mechanisms in the foot are:
 - a. the stretch of the Achilles tendon as you step down
 - b. the flattening of the arch as you step down
 - c. shock-absorption by the heel
3. Walking has the foot roll to the toes.
4. Before 1970, consumers wore rubber-soled shoes with canvas tops.
5. Waffles soles were introduced in 1972.
6. Most shoe changes involve color and gimmicks.

Teacher Notes: Engagement Phase of the Learning Cycle

A selection of used athletic shoes, which have been sawed lengthwise using a power saw, is needed for the class. One-half of a shoe per two to four students is necessary. At least two brands are needed for comparison. For a class of 32, one would need at least 4 pairs of old shoes consisting of at least two different brands. The activity should take one class period to allow for discussion of the data. Students may have shoes that they have out-grown or try the Goodwill store. Baking soda is an excellent deodorizer!

If you cannot get these old shoes cut lengthwise, use them whole and modify the activity to explore the parts of a shoe using the following data table:

Shoe Number _____ : Brand _____

Outsole:	Color(s)	Tread	Thickness	Special Features
Midsole:	Color(s)	Thickness	Texture	Special Features
Insole:	Color(s)	Thickness	Texture	Special Features
Heel Counter:	Color(s)	Height Above Midsole	Rigidity	Special Features

Answers to Conclusion Questions:

1. Answers will vary depending upon the types of shoes and the age of the shoes. It is hoped that the used shoes will show compaction of the insole and midsole at the heel and ball of the foot.
2. The insole is thickest at the arch and thinnest at the heel or ball of the foot.
3. The thickest part of the midsole is near the heel area and the thinnest is under the toes.
4. Air pockets are for absorbing shock.
5. Answers will vary. Almost all shoes have some kind of air-cushioning system.
6. Students may not be able to answer this question. They will be able to do so after the module is finished. See “Buying Shoes” at the end of this module. NOTE: Do not spend much time discussing the terms in “Parts of a Generic Athletic Shoe”. This serves as a reference page for them.

Short Evaluation for Introduction to Athletic Shoes and Engagement Activity:

Have students post their foot prints on a bulletin board and have the class try to classify/group the prints into: normal, flat foot, and high arch. Ask each to make some generalizations about the groupings in a short paragraph. Ask them to also explain what the foot does when it strikes the ground in running or walking for one of the groups of prints. Each paragraph must include the three energy-storing mechanisms in the foot. The concluding paragraph must describe what happens to the shoe (insole, midsole, and outer sole) after miles of supporting that particular foot.

Safety Notes:

- Goggles must be worn at all times.
- If any of the chemicals in this activity should contact the eye, rinse the affected area with water for 15 minutes and seek medical attention.
- There is usually no danger in handling the glue putties but students should wash their hands after use. Borax may cause allergic reactions in some students. Students can determine their sensitivity to the putty by touching a small amount. If redness or itching occur, wash the affected area with a mild soap solution. Avoid further contact.
- Do not ingest any of the putties
- Glue putty does not stick readily to clothes, walls, or carpet but watermarks can be left on wooden furniture. If a spill occurs on carpet, apply vinegar on the spot and follow with a soap and water rinse.
- Glue putty will keep for a time if stored in a plastic bag. Discard any putty in the waste can when finished.
- Liquid latex contains ammonia. Ammonia or its vapors can damage the eyes. It is recommended that contact lenses not be worn when working with ammonia containing products.
- When liquid latex sets, there is no easy way to remove it from hair or fabric. Wear old clothes, aprons or smocks when working with latex.
- Some students may be allergic to latex. They should NOT participate in parts of the activity involving latex.

Teacher Notes: Exploration of the Learning Cycle Compounding Glue Polymers and Latex

Students are to work, in groups of four, as a team during the rest of the activities in this module. You may assign the groups or have a random selection by using a deck of cards. Safety goggles must be worn when mixing the glue putties or latex.

Days 1&2&3 are for 75% glue and 25% water mixtures and all the testing. Days 4&5 are for 50% glue and 50% water mixtures and all the testing.

Prepare the outer soles by cutting black synthetic rubber from wall base into footprints that are about 15 cm long. Using silicon caulk, place a bead of caulk around the outer edge of the outer sole. You may let this dry and add a second layer of caulk on top of the first or try to carefully put two layers of caulk one right after another. A third layer may be necessary. Each team of students needs one outer sole. The outer soles are to be used later and not during the first five days.

Place paper towels and tubs of water around the room to allow for easy clean-up. Students should press the glue mixtures, in their hands, over paper towel-covered work areas. Aprons are advised for some students!

4% Borax Solution: Mix 40 grams (1/3 cup) of laundry Borax in 1 liter of water. Stir. Each team of four will need 140 mL of borax solution. This is assuming they do not spill any!

Days 1&2&3:

75% Glue and 25% water: Mix 750 mL glue with 250 mL water. (If you have a 2 liter bottle, mix up two liters of mixture at one time.) Add a few drops of green food coloring. Stir or shake. Each team of four will need 150 mL of this mixture. They are making 30 mL of the plain glue/water mixture and four with additives.

Additives have interesting and varying affects on polymers. The following is a general description of each:

- a. addition of water - more flexible, more pliable, less viscous
- b. talc or talcum powder – drier, more flexible
- c. calcium carbonate – drier, less stretchy, grittier
- d. vegetable oil – more flexible, softer
- e. talc and vegetable oil – smoother and more stretchy, more bouncy

Students will make 30 mL of the glue mixture with one teaspoon or 5 mL of the additive from the above list. Make sure the students add the additive before the borax solution.

Days 4&5:

50% Glue and 50% water: Mix 500 mL glue with 500 mL water. (If you have a 2 liter bottle, mix two liters at one time.) Add a few drops of red food coloring. Stir or shake. Each team of four will need 150 mL of this mixture. They are making 30 mL of the plain glue/water mixture and four with additives.

Students will make 30 mL of the glue mixture with one teaspoon or 5 mL of the additive from the above list. Make sure the students add the additive before the borax solution.

Using “push pumps” on plastic liter or two liter bottles simplifies the dispensing of glue/water mixtures. It is possible to get pumps that deliver about 30 mL of the glue mixtures. The addition of a pump type nozzle allows one to dispense the mixture with less waste. If dispenser bottles are not available, do not put glue mixtures in graduated cylinders. Use pre-marked plastic 3 oz. cups. Use a permanent marker to make a line at the 30 ml volume.

Materials for Days 1-5: Elmer’s® Glue-All, talc or talcum powder, calcium carbonate (powdered chalk (not dustless)), food coloring, 4% borax solution, small plastic 3 oz. cups (can be reused), stirring craft sticks or spoons (can be reused), sandwich-size zipper-type bags (10/team), graduated cylinders or marked plastic cups, felt-tip markers, 1 liter or 2 liter plastic bottles, pump-type nozzle to fit the bottle, goggles, aprons are optional, **AND the testing materials listed under each test.**

The tests are all based on 30 mL of the glue mixtures. However, there will be some variation in mass due to some of the mixture being lost in preparing the samples while additives are being added. Samples will vary from 30 grams to over 40 grams. If one wants more precision, then a balance to measure out exactly 30 grams would be recommended.

NOTE: Evaluation takes place at several places during this module. The teacher may choose to use several of our mini-evaluations (after each test) or after all the testing is complete. There are mini-rubrics for each. Each test concludes with a set of questions for the students to answer. The last question in each set requires a longer paragraph of written explanation. These are placed as mini-evaluations for the teacher. The final project assessment is located at the end of the module.

Fluidity Testing:

Materials: (for each team) four plastic Petri dishes (60x15 mm) either the lid or bottom or the bottom of a yogurt cups (cut off the top leaving a 2 cm edge), samples of each glue putty, second hand on a wall clock or wrist watch

The more fluid a polymer, the faster its surface will recover when deformed. However, the more fluid a putty, the less durable it may be. When choosing a material for insoles and midsoles, students should try to balance recovery time with durability. The most fluid polymer may be impractical to use in a shoe.

Example of fluidity data:

Polymer Tested	Distance From Edge of Ball to Edge of Dish (mm)	Time to Flow to the Edges of the Dish (sec. and min.) Time exceeds 5 min, see sketches below	Distance from edge of putty to edge of dish at 5 min (mm)	Rate in mm/min. or mm/sec.
75% glue/water	20	5	15	1mm/min

The calculation of rate is the total distance traveled divided by the time. In the above example, the total distance was 5 mm/5 min = 1mm/min.

Evaluation of Fluidity Testing:

Category	4 points	2 points	0 points
Data Table	Complete	Partially filled	Lots of missing data
Calculation of rates	Correct	Mostly correct	Mostly incorrect
Sketches (for exceeding 5 min tests)	Complete	Mostly complete	Incomplete
Questions	Complete	Mostly complete	Incomplete
Answers to questions	All appropriate	Mostly appropriate	Mostly inappropriate

Answers to the questions:

1. The fastest flow rate is for 50% glue/water and oil or oil with talc. Rate answers will vary. The slowest rates are for 75% glue/water mixtures. Rates will vary. None of the 75% samples reached the edge in 5 min.
2. The addition of oil seemed to increase the fluidity of a putty.
3. The polymer with the most fluid characteristics might be used for the midsole under the flexing part of the foot. However, durability must also be taken into consideration. Student answers should show logic in this decision.

Optional Demonstration:

1. Attach a ring with a clamp near the top of a ring stand.
1. Cut the top off of a 2-liter bottle, just above the label, to act as a funnel. Place the top of the bottle in the ring to form a funnel.
2. Place a sample of any of the putties in the funnel. Place this in a readily visible location in the room. Allow the putty to flow through the funnel during the class period.

A small dish can be placed under the funnel to catch the flowing putty. Note: Several putties of different colors or of different types can be placed in the funnel at the same time. Each will give a different visible "flow" result. Putty can be removed from the dish and placed in the funnel again.

Texture and Consistency Testing:

Materials: 10 samples of each glue putty

Students will choose a favorite polymer. However, the majority of the polymers used in their shoe sole will not come into contact with the foot. They should realize that other characteristics must be relied upon when picking a polymer for use in the midsole. Only the sock liner and the upper part of the shoe actually contacts the foot. Students will also have a favorite color, or favorite color combinations. They may choose to use food coloring to dye any parts of the shoe that will be visible in the shoe when they are in the assessment part of the module. Color and style does sell shoes! If students check shoe stores, they will find about every 6 to 8 months, shoe models change. The change maybe in color, trim, or in overall design. This is a very competitive business!

Evaluation of Texture and Consistency Testing:

Category	4 points	2 points	0 points
Data Table for texture	Complete	Mostly filled	Incomplete
Data Table for Stretchiness	Complete	Mostly filled	Incomplete
Questions	Complete	Mostly complete	Incomplete
Answers to questions	All appropriate	Mostly appropriate	Mostly inappropriate

Answers to questions:

1. Answers will vary. Students seem to prefer the runny and softer putties.
2. The softer putties are less suitable for the midsoles under the heel of the foot.
3. Compounding is extremely important. They physical properties of polymers can be altered to fit the demands of the customer. See the teacher notes on “What is Compounding?”

Strength Testing:

Materials: (for each team) glue putty samples, PVC tubing in 30 cm length (1.25 in ID), marble about 2.54 cm diameter or a glass cube from Michaels, 6 or 8 oz plastic cup (yogurt cups work well), ring stand and clamp to fit the tube, meter stick

A good athletic shoe must have cushioning, flexibility and control or stability for the foot. During footfall, the body weight strikes on the heel, shifts forward over the midfoot, and rolls forward onto the toes. A shoe must allow for flexibility of foot movement while at the same time, absorbs shock. Students need to pick a flexible polymer for the midfoot and forefoot sections of the midsole. However, this polymer must still provide good shock absorption. As an athlete rolls forward onto the metatarsal bones of the forefoot, the force exerted may be between four and seven times a runner’s body weight. This could be over 1000 pounds for a 150-pound runner. The muscles spread the stress evenly across the metatarsals of the forefoot, absorbing the surge of power that propels the foot off the ground for the next stride.

Evaluation of Strength:

Category	4 points	2 points	0 points
Data Table	Complete	Partially filled	Lots of missing data
Questions	Complete	Mostly complete	Incomplete
Answers to questions	All appropriate	Mostly appropriate	Mostly inappropriate

Answers to questions:

1. One would expect to see all of the 50% mixtures break before 50 cm. The 75% mixtures with oil, oil and talc and calcium carbonate will break between 50 and 70 cm.
2. The stronger polymers would be appropriate for the midsoles to withstand impact due to objects on the ground. One would not like his/her shoe to have the midsole crack under the foot while running or walking.

Impact and Elastic Recovery Testing:

Materials: (for each team) samples of each glue putty, four yogurt cups that have been cut down to 2 cm in height, PVC tube that is 60 cm in length with a ID of 1.25 in, bolt (1/2" diameter hexagon top, 3" long), metric ruler, ring stand and clamp, clock or watch

If a runner covers only 15 miles a week, his/her foot strikes the ground about one million times a year. Each time a foot lands on its heel, it undergoes considerable shock. The heel bone reacts to this by first rolling, swaying, and then finally tilting slightly over towards the outside of the foot. The actual shock of heel contact creates an impact of up to three times body weight. All this impact is transferred upward. If shoes don't absorb the shock, the ankles, shins and knees must take the force. Runners commonly suffer from injured knees, inflamed tendons, shin splints, and blisters. They are willing to pay for shoes that will help them avoid the pain and down-time due to sports related injuries. The midsole is responsible for shock absorption. The midsole may lose some of its shock absorbing ability after several hundred miles of pounding by the foot.

Students need to find not only a polymer that absorbs shock, but one that rapidly returns to its original form to take the repeated abuse of each foot fall. A good shock absorbing surface deforms when struck and this is represented by the indentation made in the polymer's surface by a large bolt. The surface must also be able to rapidly return to normal. Students should find that the best shock absorbers provide the least amount of bolt "bounce" after collision with the polymer surface. However, if a surface stays deformed for long periods of time, it will not be able to transfer the compression energy back to the forward spring of the foot, or be ready for the next impact. Depending on the recipes of polymers chosen, students may not be able to choose a polymer which excels at both absorption and elastic recovery. They may have to pick a polymer that at least provides a little of each characteristic.

Example of Impact and Elastic Recovery Data:

Polymer Tested	Depth of initial indentation (mm)	Surface Recovery Time in min	Indentation remaining if any (mm)	Rate of Recovery in mm/min
75% glue/water	3	5	1	.4mm/min

The rate is determined by taking the depth of the indentation divided by time. The total indent was 2 mm divided by 5 min. = .4 mm/min.

Evaluation of Impact and Recovery Testing:

Category	4 points	2 points	0 points
Data Table	Complete	Partially filled	Lots of missing data
Calculation of rates	Correct	Mostly correct	Mostly incorrect
Questions	Complete	Mostly complete	Incomplete
Answers to questions	All appropriate	Mostly appropriate	Mostly inappropriate

Answers to Questions:

1. The best shock absorbers are 50% with calcium carbonate, oil and oil with talc based on depth of indentation.
2. The quickest recovery occurs in 50% and 75% with oil or oil with talc.
3. The 50% with oil and oil with talc are usually the best. Look at their data for logic.

Elasticity/Bounce Testing: (This is recommended to be done last since the samples may pick up dirt.)

Materials: (for each team) samples of putty to be tested, meter stick, 3 surface materials such as classroom floor tile, asphalt or cement, grass

Before the putty ball is dropped, it has potential energy. As it falls, the kinetic energy is changed into kinetic energy. On the way back up, the kinetic energy is changed back into potential energy. However, the putty will not return to its original dropping position. There is energy lost during the interaction of the putty ball and the surface on which it lands. Part of the energy is converted into heat and sound. During impact, the shape of the putty ball changes. The ball deforms and partially restores itself. This shape change takes energy, just as stretching a rubber band does. The flattening is similar to compressing a spring. If the ball stays deformed, the energy is not returned to kinetic energy in the ball. The surface is also deformed on impact. The height of the bounce is determined by how much energy of compression is returned as the shape of the ball and the surface. Students may find that the harder surfaces return more energy to the ball. They must keep in mind that type of shoe they are designing. A given material may bounce better on a cement surface than on grass. They should pick a good “bouncer” for the type of surface on which their shoe is designed to be used.

Evaluation of Elasticity:

Category	4 points	2 points	0 points
Data Table	Complete	Partially filled	Lots of missing data
Questions	Complete	Mostly complete	Incomplete
Answers to questions	All appropriate	Mostly appropriate	Mostly inappropriate

Answers to questions:

1. There are no significant differences between the additives within a type of mixture. However, the 75% mixture consistently bounced higher on all surfaces. The shape of the putty ball deforms and partially restores itself on impact. If the ball stays deformed, the less kinetic energy is available for the bounce. The 50% mixture balls deformed more in this test.
2. No, the bounce is an elastic response to the drop. It does not absorb the shock of hitting the surface.
3. The midsole protecting the ball of the foot is where polymers with good elasticity should be placed.

Latex

The latex experiments are more expensive than using Elmer's® Glue-All. However, this elastomer (it is elastic or rubber-like) has some unique properties and makes an excellent study on compounding with latex. Liquid latex is packaged in ammonia which acts as a preservative. Neutralization with vinegar (acetic acid) will cause the latex to solidify into rubber very quickly. The ammonia and vinegar have irritating fumes. Latex is not considered hazardous. Caution: Some students have allergies to latex and should not do that activity.

Materials: liquid latex (25 mL per team), old tee-shirt fabric, vinegar in a spray bottle, talc or talcum powder, calcium carbonate (powdered chalk), vegetable oil, plastic cups, spoons, old newspapers, 5 yogurt cups, teaspoon

Evaluation of Latex Testing:

Category	4 points	2 points	0 points
Data Tables	Complete	Partially filled	Lots of missing data
5 Samples	All available	Some available	None available
5 Samples	All labeled	Some labeled	None labeled
Questions	Complete	Mostly complete	Incomplete
Answers to questions	All appropriate	Mostly appropriate	Mostly inappropriate

Answer to questions:

1. Answers will vary depending upon the student preferences.

Rubrics for the Exploration and Explanation – Individual Tests

A teacher might want to chat with each team about their testing and conclusions using these rubrics. Having students articulate their findings is another method of evaluation. It is not advisable to use this as a class discussion because these tests belong to the “soon-to-be-formed-company” and should be available only to the individual team members.

Evaluation of Fluidity Testing:

Category	4 points	2 points	0 points
Data Table	Complete	Partially filled	Lots of missing data
Calculation of rates	Correct	Mostly correct	Mostly incorrect
Sketches (for exceeding 5 min tests)	Complete	Mostly complete	Incomplete
Questions	Complete	Mostly complete	Incomplete
Answers to questions	All appropriate	Mostly appropriate	Mostly inappropriate

Evaluation of Texture and Consistency Testing:

Category	4 points	2 points	0 points
Data Table for texture	Complete	Mostly filled	Incomplete
Data Table for Stretchiness	Complete	Mostly filled	Incomplete
Questions	Complete	Mostly complete	Incomplete
Answers to questions	All appropriate	Mostly appropriate	Mostly inappropriate

Evaluation of Strength:

Category	4 points	2 points	0 points
Data Table	Complete	Partially filled	Lots of missing data
Questions	Complete	Mostly complete	Incomplete
Answers to questions	All appropriate	Mostly appropriate	Mostly inappropriate

Evaluation of Impact and Recovery Testing:

Category	4 points	2 points	0 points
Data Table	Complete	Partially filled	Lots of missing data
Calculation of rates	Correct	Mostly correct	Mostly incorrect
Questions	Complete	Mostly complete	Incomplete
Answers to questions	All appropriate	Mostly appropriate	Mostly inappropriate

Evaluation of Elasticity:

Category	4 points	2 points	0 points
Data Table	Complete	Partially filled	Lots of missing data
Questions	Complete	Mostly complete	Incomplete
Answers to questions	All appropriate	Mostly appropriate	Mostly inappropriate

Evaluation of Latex Testing:

Category	4 points	2 points	0 points
Data Tables	Complete	Partially filled	Lots of missing data
5 Samples	All available	Some available	None available
5 Samples	All labeled	Some labeled	None labeled
Questions	Complete	Mostly complete	Incomplete
Answers to questions	All appropriate	Mostly appropriate	Mostly inappropriate

Rubrics for the Exploration and Explanation – Grouped Tests

Students need to be accountable for the science they have just performed. This is a rubric to help the teacher and students recognize any shortcomings in the data and answers to conclusion questions. A copy of this may be given to the students prior to the testing of glue putties.

Category	3	2	1	0
Test	All tests completed	Most tests completed	Few tests completed	No tests completed
Fluidity				
Texture and consistency				
Strength				
Impact and elastic recovery				
Elasticity/bounce				
Latex				

Category	3	2	1	0
Test	Data accurately recorded	Most data accurately recorded	Little data accurately recorded	No data recorded
Fluidity				
Texture and consistency				
Strength				
Impact and elastic recovery				
Elasticity/bounce				
Latex				

Category	3	2	1	0
Questions	All answers consistent with data	Most answers consistent with data	Few answers consistent with data	No answers consistent with data
Fluidity				
Texture and consistency				
Strength				
Impact and elastic recovery				
Elasticity/bounce				
Latex				

What is Compounding?

(This section is background reading for the teacher and should be used to explain compounding to students at the **explanation** phase of the learning cycle.)

The simplest definition of a polymer is something made of many units. The units or “monomers” are small molecules that usually contain ten or less atoms in a row. Carbon and hydrogen are the most common atoms in monomers, but oxygen, nitrogen, chlorine, fluorine, silicon and sulfur may also be present. Think of a polymer as a chain in which the monomers are linked (polymerized) together to make a chain with at least 1000 atoms in a row. Polymerization can be demonstrated by hooking together hundreds of paper clips or pop beads together to form extended chains. It is this feature of large size that gives polymers their special properties. The physical or mechanical properties of a polymer depend largely on the interactions of polymer chains. Intermolecular attractive forces, molecular weight (or size of the molecule), the degree of polymer chain packing, and the flexibility of the chains all effect the properties of a given polymer.

Scientists are continually working to provide cheaper, stronger, and better polymers. One method of accomplishing this goal is through compounding or the addition of a variety of materials to a polymer while in the manufacturing process. The goal is to make the best possible product and to assure efficient and trouble-free manufacturing of the product. Almost all polymers in commercial use today contain additives. These additives change the properties and/or improve the ease of processing the polymer. The final product often performs better and can be offered at a lower cost to consumers. Research on additives is an important component of the polymer industry.

Additives may be fillers (or extending agents), reinforcers, coupling agents, antioxidants, heat and ultraviolet stabilizers, flame retardants, plasticizers, impact modifiers, colorants, curing agents, foaming agents, biocides, lubricants, and antistatic agents. Some are present in high concentrations while others are in very low concentrations. For example, since talc filled polypropylene has improved heat resistance, a washing machine pump housing may be 40% talc and 60 % polypropylene. Fillers can increase the strength and reduce the amount of polymer needed for a product. Inorganic fillers such as talc, calcium carbonate, barium sulfate, magnesium oxide, aluminum fibers, glass, and carbon black are commonly used with thermoplastic polymers (polymers that can be reheated and reformed). Thermosetting polymers including rubber products (those that do not soften with heat and can not be remolded) require additives to reduce shrinkage during setting. Brittle plastics can be combined with more flexible polymers to help prevent cracking or fracturing.

Some plastics are made with blowing agents. When gases such as carbon dioxide, nitrogen, or air are directly dissolved in the polymer melt, a product is formed with a reduced density such as polystyrene foam containers. Other blowing agents have low boiling points such as pentane or hydrazine which can liberate gases during reactions

involving heat. Stabilizers act to minimize degradation of plastics by light, heat, and microorganisms.

About 85% of all additives are performance additives. They are added during the manufacture of a finished product. Fillers such as ground limestone, clay and glass fiber, lower the cost of a fabricated product while improving its performance. They can reinforce and increase strength, act as coloring agents, extend and dilute, and alter processing characteristics. Coupling agents are often needed to form a good bond between the filler and the polymer. Plasticizers increase the flexibility and workability of rigid plastics such as vinyl products (made of poly(vinyl chloride)). They act by reducing the forces that hold polymer chains close to one another and allow chains to slide more easily over one another.

Common flame retardants used with polymers are bromophenols and antimony trioxide. They are polymerized into the polymer resin or are attached by chemical reaction to the finished product's surface. Since polymers are good insulators, they build up static charges. To counteract this problem, antistatic agents which absorb moisture from the atmosphere provide charge reducing moisture on the polymer. Polymer films or sheets tend to stick together due to an accumulation of static electricity and the molecules on one film become physically mixed with those of another film. Antiblocking agents, such as soap additives, waxes or fluorinated polymers can be used as release agents to prevent films from sticking together.

Emulsifiers are added to latex paints and some adhesives to keep the product mixed and viscous. Some thermosetting polymers tend to sag while curing in a compression mold operation. Thickening agents such as calcium carbonate, are added to increase the viscosity of the polymer. The thickening is thought to be due to the formation of a continuous network that is physically, rather than chemically linked together.

Raw rubber is made up of huge hydrocarbon chains. It flows on standing and does not retain its shape. To make rubber truly useful, its chains must be permanently linked together to increase its strength. Rubber is heated in the presence of sulfur to create sulfur linkages or bridges between rubber chains. This process is called vulcanization or crosslinking. Charles Goodyear, in 1839, discovered this additive by accidentally spilling a mixture of latex and sulfur on a hot stove! This discovery is hailed as one of the most celebrated "accidents" of history. However, he died in 1860 poor and in debt. He had troubles with his business deals, and legal battles with patents and licensing procedures. His son Charles, Jr. inherited his inventive talent and built a small fortune on shoemaking machinery. The automobile tire of today has more additives than just sulfur. Think about carbon black, nylon cord, fiberglass, and steel belts to name a few!

Silly Putty® is one of the success stories of compounding. Over 200 million eggs of Silly Putty® have been produced since 1950! It is made from silicone oil cross-linked with boric acid. Silicon oil is a polymer chain of silicon and oxygen atoms with methyl groups on the silicon-oxygen chain. It was discovered when James Wright of General

Electric was working on developing a synthetic rubber during World War II. The heated mixture formed a gooey plastic and refused to take a shape like solids. It flowed like a liquid but would break or snap when pulled hard. It made a terrible substitute for rubber for automobile tires! Ruth Fallgatter started selling it in small packages in 1949 and then lost interest. Peter Hodgson decided to pursue his marketing idea of packaging it in plastic eggs. Within three days after its appearance at the 1950 International Toy Fair, he had more than 250,000 orders. Silly Putty® is an elastomer or it has elastic properties. It bounces like a ball but the weaker coordinate covalent bonds are easily broken when the putty is stretched or pulled hard. (*ChemMatters*, February 1998)

Integration of History with Science:

The integration of history and science is appropriate at this time. The following people or companies have influenced the development of the modern athletic shoe:

Joseph Priestly – discovered the milky liquid (latex) from trees grown in Malaysia and the Dutch East Indies could “rub” out pencil marks and he used the term “rubber” to describe this action.

Wait Webster – invented the process of attaching rubber to soles of shoes and boots

Nathaniel Hayward – baked sulfur with gum to produce rubbery, but not sticky surfaces while exposed to heat or the sun

Thomas Crane Wales – was a shoe manufacturer of the waterproof boot

Candee Manufacturing Co. of New Haven, CT was the first to produce a sneaker with laced canvas uppers and vulcanized rubber soles.

Spalding Co. invented the rubber sneaker sole with molded suction cups for better traction.

Henry McKinney – of the National India Rubber Co. invented “Keds”

Books that help students with their research are:

Caney, Stephen, *Invention Book*, Workman Pub., N.Y. 1985

Jones, Charlotte Foltz, *Mistakes That Worked*, Double Day, 1991

Standish, Bob, *The Unconventional Invention Book*, Good Apple, 1987.

McCormack, Alan, *Inventors Workshop*, Fearon Teacher Aids, 1981.

Teacher Notes: Elaboration of the Learning Cycle

The link of science and technology, careers in industry, basic scientific research, good record keeping, use of the scientific method, language arts, and cross-curricular integration is included in this module. One can expand on these ideas with environmentally friendly packaging of the final product, library or Internet research on natural rubber and synthetic rubber, and incorporating drama, fine arts or video production.

The prices provided for the shoe companies are designed to make the wholesale price of a shoe to be about \$50 based on four 30 mL batches of putty and three batches of

latex per prototype. When the group calculates the cost, they must remember to account for the fact that 50% glue mixture is only 50% glue and 50% water.

All shoe companies get their chemicals from the same source. Here are the “wholesale” prices for the following: (These prices are rather inflated!)

White glue	\$.50 per mL
Latex	\$1.00 per mL
Talc	\$2.00 per teaspoon
Calcium carbonate	\$1.00 per teaspoon
Oil	\$3.00 per teaspoon
Borax solution	\$.25 per mL
Water	\$.05 per mL

Calculate the cost of the prototype and then double the price to get the retail price for a pair of shoes.

Here is an example of a possible shoe cost:

4 samples of 50% glue/water = 30 mL x 4 = 120 mL but only 60 mL are glue and 60 mL are water.

Glue = \$30.00

Water = \$0.60

½ teaspoon talc = \$1.00

1 ½ teaspoon oil = \$4.50

borax solution for 4 samples = \$10.00

latex for insole = \$15.00

Total = \$61.10 The retail cost must be \$122.20.

Scoring Rubric for Evaluation Written Reports

Category	4	2	0
Corporation Grade			
Name of company reflects shoe design and originality	Accomplishes both	Accomplishes one	Accomplishes neither
Report Grade			
Organization	Organized	Partly organized	Not organized
Each team member contributed to the written report.	All team members contributed.	More than half of the team members but not all contributed.	Half or less of the team members contributed.
Use of grammar and spelling.	Grammar and spelling were excellent.	Several mistakes in grammar and spelling.	Many mistakes in grammar and spelling.
Use of correct terminology	All terms used were correct.	Some of the terms were incorrect.	Most of the terms were incorrect.
Explanation of putties selected based on test results and explanation for the insole. Use of shoe sole outline.	Explained three or more tests done on polymer properties used in final shoe design. Used shoe sole outline.	Explained two of the tests done and discussed insole. Used shoe sole outline.	Explained only one test done but did not discuss insole. Did not use shoe sole outline.
Graphs of test results.	Three graphs were displayed of the tests discussed above.	Only two graphs were displayed of the tests discussed above.	One or none graphs displayed.
References cited and quoted.	Two references were cited and quoted.	Only one reference was cited and quoted.	No references were cited.
Calculations for the retail price of the shoe.	Itemized costs of materials used to make the new shoe soles and final selling price to make a 50% profit. .	Provided only some of these costs.	Did not provide any costs.
Total of Points (36 Possible)			

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Brunick, Tom, “Coming to Terms”, *Tennis*, Vol. 30, No. 1, May 1994.

Goldfarb, Bruce, “Color In a Capsule”, *ChemMatters*, February, 1998.

Taylor, Beverley, James Poth and Dwight Portman, *Teaching Science With Toys – Physics Activities for Grades K-9*, Terrific Science Press, Miami University, Ohio, 1994.

Wolkomir, Richard, "In Search of the Footwear Ferrari", *Smithsonian*, September, 1989, pp. 94-104.

“Adding Additives (or how to change your polymer properties)”, a presentation by H.E. Alberti at a DuPont Honors Teachers Workshop, New Orleans, 1997.

“An Amble A Day”, *Consumer Reports*, Vol. 62, Issue 7, July 1997.

Basic Compounding and Processing of Rubber, edited by Harry Long, Rubber Division of the American Chemical Society, Akron, Ohio, 1985.

“Can One Shoe Fit All?”, *Women’s Sports & Fitness*, Vol. 18, Issue 1, Jan./Feb. 1996

Chain Gang – The Chemistry of Polymers, edited by Mickey Sarquis, Director, Center for Chemical Education, Terrific Science Press, Miami University, Middletown, Ohio, 1995.

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“The Sport Shoe Buyer’s Guide”, *Men’s Health*, Vol. 12, Issue 1, May 1997.

<http://web.mit.edu/invent/www/inventorsA-H/bowermanknight.html>

<http://www.saucony.com/bio/html>

<http://mayoclinic.com> (Mayo Foundation for Medical Education and Research)