NO MORE LEAKS!

A Process-Oriented Lesson Exploring the Invention and Chemistry of Disposable Diapers

by Ellen Schiller and Ellen Yezierski

High school chemistry can be intimidating to some students, so it is critical that we engage students in nonthreatening preparatory investigations during middle school. Based on the learning cycle model (Bybee and Landes 1990), this lesson invites students to investigate disposable diapers. As they explore the properties of sodium polyacrylate, a super-absorbent polymer used in disposable diapers, and how it reacts when exposed to water and simulated urine (colored salt water), students practice many inquiry skills: observation, measurement, graphing, and data analysis. In addition, the student investigation guide (see Activity Worksheet) models scientific writing, much like

what is expected in high school science lab reports, and several extensions are offered for further student research. Through this process, students will have an opportunity to see that chemical research can result in substances with useful applications.

On the particulate level, the process by which sodium polyacrylate absorbs water is too complex for middle school students. Too often, complex concepts are "dumbed down" for lower ages, which may lead to misconceptions and confusion. Therefore, this lesson focuses on the development of student inquiry processes using an intriguing material (viewed macroscopically), rather than the structure of the polymer and its interactions with water on a particulate level. Students investigate the material in the context of a humorous scenario (leaky diapers); humor can be a powerfully engaging learning tool—one that allows students to stretch their skills.

The process skills associated with this lesson are emphasized in the inquiry standards contained in the *National Science Education Standards* (NRC 1996, p. 150). This lesson works well at the beginning of the school year, when many students would benefit from a reintroduction to laboratory science skills.

Invitation to learning (Day 1)

Hide a disposable diaper in an opaque box or bag, preferably one big enough to disguise the diaper's size and keep students guessing for a few minutes. Tell the class, "Inside this box is one of humankind's most convenient inventions, something that has made life easier for many people. Do you have any idea what it is?" Students will often suggest items they use every day: a pencil, pen, calculator, cell phone, or laptop. They may guess items that occur naturally, such as magnets or water, which offers the opportunity to discuss what an invention is. If they have trouble guessing, you can offer to answer yes/no questions that students pose. Kids will ask, "Is it made out of paper?" or, "Can you wear it?" These questions/answers will eventually lead them to guessing that it's a diaper. As you pull it out of the box, there are always grins and giggles. Limit the discussion to five to ten minutes.

Once the initial frivolity has passed, ask the class what they know about disposable diapers and list their responses on the board. Some might mention that disposable diapers overload landfills and are not as ecofriendly as cloth diapers. From their experiences as babysitters or older siblings, some students may be familiar with the features of disposable diapers—that they expand when wet or that gel sometimes leaks out of the diaper's lining. They likely know little about the actual materials used in diapers. At this point you can distribute Figure 1 to students and ask them to add any new knowledge about diapers to their items listed on the board. If you plan to incorporate student research on diapers or inventions, you can lead students through a KWL.

Organizing your class into pairs, have students spread old newspapers on their work surface and distribute the items on the materials list (Figure 2). This investigation will be messy, and the paper will help with cleanup. At the end of the lesson, students can gather the disposable materials into the center of the newspaper and take the bundle to the trash can. Never

FIGURE 1 Where did disposable diapers come from?

The first prototype of a disposable diaper was developed in Sweden in 1942. Over the next two decades, various researchers and companies sought to improve their design and effectiveness. In 1956, Victor Mills of Proctor and Gamble began work on the development of a better disposable diaper. The resulting product, Pampers, was launched in 1961. Disposable diapers surged in popularity in the 1970s, with manufacturers competing to improve quality and attract customers. Complaints from pediatricians and parents about the bulky weight of disposable diapers placed pressure on manufacturers to trim the size.

Super-absorbent polymer chemistry dates to the early 1960s. Chemical engineers Billy Gene Harper and Carlyle Harmon filed the first patents for sodium polyacrylate in 1966. It was first used in diapers in 1982, greatly reducing the need for thick padding and creating the thin, yet highly absorbent, diapers we see today. In the competitive diaper market, manufacturers continue to improve their products, but sodium polyacrylate has remained a standard ingredient. Nearly 1,000 patents related to diaper design have been issued (Richer Investment Consulting Services; Schueller; Rohrig 2002).

...and where are they going?

Disposable diapers have borne a good deal of criticism as society becomes greener. They are frequently lambasted for the space they consume in landfills, and their production includes the use of petroleum and other nonrenewable resources. Cloth diapers are made from renewable cotton and enjoy a long life span, but they require water and energy in the cleaning process, and many parents consider them less convenient.

Activity Worksheet

Student investigation guide

Objectives

- Determine the relationship between diaper performance and saltwater or "urine" concentration.
- Use appropriate measuring techniques.
- Prepare a graph to describe the relationship between the dependent and independent variables.
- Summarize and display data in an orderly fashion.

Procedure

To determine the relationship between diaper performance and saltwater concentration, you will test the diaper polymer with distilled water and various "urine" solutions. Use the data table to record your measurements and observations.

Use a graduated cylinder to measure and add 1 mL of diaper polymer to each of five plastic cups. Measure the mass of each cup and record it.

Obtain about 150 mL of distilled water (control) and 150 mL of each of the "urine" solutions in separate labeled containers. Before adding the water and "urine" to the cups, consider how you will compare the performance of the polymers. Keep in mind that diapers fail when urine leaks out and gets the baby's clothes (or parents) wet. There is a limit to how much water or "urine" the polymer can hold. **You and your partner should agree upon how you will know when the diaper polymer fails.** It fails when it cannot absorb any more water or "urine." The failure point could be (1) when the cup is turned on its side, the polymer and water mixture pour out, or (2) when liquid water "leaks" out of the gel or pools.

Using the pipette, add water to the first cup containing the polymer. Continue adding small amounts of water until you reach the failure point. Measure and record the mass of the cup containing the polymer and water at the failure point. In each of the other cups, repeat the experiment with one of the four "urine" solutions. Be sure to record your results. You will need to subtract the mass of the cup from the mass of the polymer, water, and cup at the failure point.

Data table

Solutions	**Starting mass (in grams) of plastic cup and 1mL of diaper polymer**	**Ending mass (in grams) of cup, polymer, and solution at failure point**	**Amount of solution absorbed (in grams)** Subtract starting mass from ending mass
Distilled water (control)			
0.5% saltwater "urine" solution			
1 % saltwater "urine" solution			
2 % saltwater "urine" solution			
5 % saltwater "urine" solution			

Prepare a graph with "salt concentration (%)" on the *x*-axis and "mass of polymer + water/"urine" (g)" on the *y*-axis. Plot the points and sketch a line or curve through the points (whichever fits better). Be sure to give the graph a title and label the axes. Answer the follow-up questions.

Follow-up questions

- Which variable(s) did you control during the experiment?
- Examine your observations and graph. Describe the results of your experiment in words.
- Is there a relationship between diaper performance and "urine" concentration? If so, what is it?
- Real urine contains NaCl and other dissolved salts. How do you think the salt content in babies' urine affects the diaper performance? Use your data to support your answer.

dispose of super-absorbent polymers in a sink because a clog can easily form. Students should wear chemical splash goggles throughout the lesson.

Have students initially explore sodium polyacrylate by pouring a beaker of tap water into one diaper, noticing the diaper's super-absorbent properties, and observing how much water the diaper can hold before it leaks onto the newspaper. Students can cut open the lining and notice that there is a gel-like substance inside the diaper. Students should also examine a dry diaper; they can carefully cut open the lining in the crotch of the diaper with scissors and gently pull apart the padding to find the crystals. The dry crystals are quite fine and they will float into the air if students dig into the padding too vigorously. While sodium polyacrylate is not toxic, students should always avoid inhaling particles into their lungs. If you are worried about safety, students can pull out the padding inside a large resealable bag.

While students are exploring the diapers, ask them to share what they have observed. Pairs could report their observations on the board and groups can add to or modify the class data. What is this crystalline powder? What properties does it appear to have? Students should note the super-absorbent properties of the sodium polyacrylate. From a consumer point of view, leaky diapers are undesirable; therefore the diaper industry is continually working to improve diaper function and attract more "brand loyal" customers. Tell the class that it's time to become serious diaper scientists! Here you can introduce diaper industry quality control tests such as "Demand Wettability" or "Gravimetric Absorbance," which measure "Absorbency Under Load (AUL)." For example, AUL measures the effect of a baby sitting on a wet diaper. Quality engineers add 0.9% saline solution to sodium polyacrylate, while subjecting the sample to pressure equivalent to 21,000 dynes, or about 0.021 kg/cm^2. If the diaper has an absorbency of at least 24 mL/g after one hour, the quality is considered acceptable (Schueller). An internet search will yield much additional diaper industry research.

FIGURE 2 Materials list and advance preparation

Students will be testing the diaper polymer's ability to absorb distilled water as well as different concentrations of saltwater (simulated "urine"). You will need to prepare saltwater solutions with these NaCl concentrations (by mass): 5%, 2%, 1%, and 0.5%. To make enough for 14 pairs of students, begin by dissolving 105.5 g of NaCl in 2 L of distilled water. Add several drops of yellow food coloring to simulate urine. This is the 5% salt solution for the experiment, as well as the stock solution (or "starter") for preparing the more dilute solutions. For the 2% solution, measure 400 mL of the 5% solution, pour it into a 1 L container, add distilled water to the 1 L mark, and mix well. Starting with the stock solution, use the dilution guide below to make the 1% and 0.5% solutions in the same manner.

Dilution guide for solution preparation

Concentration (%)	Volume of 5% stock (mL)
2	400
1	200
0.5	100

Quantities listed below are for each pair or group of students working together:

- newspapers to protect work surface and facilitate cleanup
- 2 disposable diapers
- scissors
- triple-beam or electronic balance
- 2 beakers or other scaled measuring containers
- pipette/medicine dropper
- distilled water
- teacher-prepared simulated urine (see above—provide about 150 mL of each solution for each pair, in labeled containers)
- 5 clear plastic cups (can be rinsed and reused with other classes, as long as the sodium polyacrylate is not disposed of in the sink; have students dump all the cup contents into the trash before rinsing)
- sodium polyacrylate "diaper polymer" (5 mL per pair), available from Educational Innovations at *www.teachersource.com* or Flinn Scientific at *www.flinnsci.com*. The 16 oz. container is sufficient for 5 classes of students. You may wish to purchase a larger bulk package for a better unit price; any leftover powder has a long shelf life, if kept dry, and can be saved for use the next year.
- graduated cylinder
- chemical splash goggles (1 per student)
- student investigation guide and pencil for each pair or student

FIGURE 3 Diaper polymer with water and salt solutions at their failure points

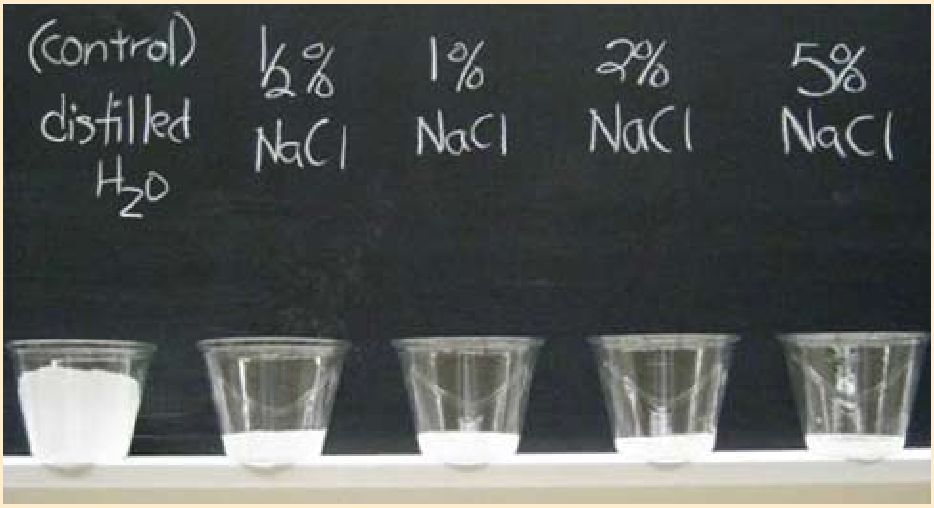

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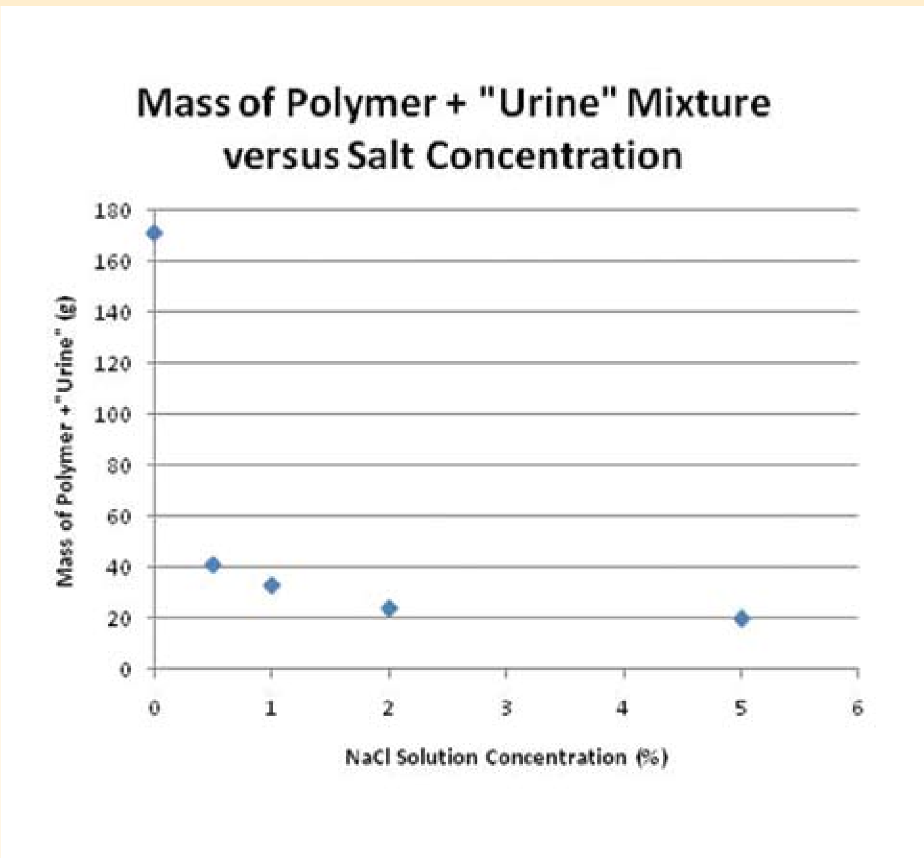
FIGURE 4 Typical student data graphed for analysis showing the relationship between saline polymer mass



Student investigation and teacher facilitation (Day 1 continued or Day 2)

The student investigation guide (see Activity Worksheet) will help students prepare for the experiment, carry out procedures, analyze data, and apply results; refer to it for details of the investigation. Students work in pairs to simulate a diaper's function—absorbing water and urine—and investigate the conditions under which diapers fail. The notion of "diaper failure" (leaky diapers) is surely funny, but also an area of continued serious research in product development.

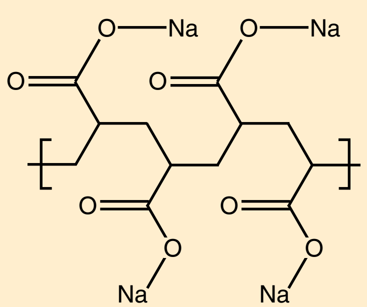
As you facilitate this investigation, help students use measuring devices properly, consider how to control variables, and prepare the data table and graph. The amount of direction depends on students' proficiency with inquiry. For example, students may struggle to determine when each of the samples reaches its maximum absorbency. To help them control variables, remind them to add the "simulated urine" slowly and be consistent in their method of determining the point at which the polymer fails. As a guideline, the authors tipped the cup containing the polymer/water mixture and considered it "failing" when droplets of water leaked out of the gel and slid out of the cup. You should practice this beforehand without students to be familiar with the polymer's behavior when it fails.

Students should find that the higher the salt concentration, the less water the polymer can hold. Figure 3 shows the control cup and the four concentrations of "urine" cups at their typical "failure points." Students should see how the salt concentration affects diaper performance (simulating a real diaper's performance with baby urine). The nature of the relationship between polymer absorption and salt concentration is even more obvious when graphed. Figure 4 shows a graph of typical results. Students may notice that when water or salt water is added to the polymer and the mixture sits for a few minutes, it thickens and can absorb more. That is a helpful quality in diapers. Remind students to try to control the time between pouring the water or salt water and measuring how much solution each sample held.

Scientific explanation for teachers

The interesting relationship between the "urine" concentration and polymer performance is caused by the polymer's interactions with water and sodium ions. Sodium polyacrylate (Figure 5) chains exist as coils with random shapes. When the polymer is placed into water, the sodium ions go into solution, leaving negatively charged carboxyl groups (COO^-) that repel each other, thus uncoiling the chains. Water molecules adhere to the charged groups (through hydrogen bonding) along the chains and "swell" the coils. In the presence of a saltwater solution (or urine), the sodium ions, not water molecules, bond with the carboxyl groups. The chain coils and squeezes out the water (Shakhashiri 1989, p. 371). This is why diapers hold less urine than they do water.

FIGURE 5 Structure of sodium polyacrylate



Applications and research opportunities

This investigation of disposable diapers suggests several questions for follow-up student research:

- How do different brands (and sizes) of diapers compare in terms of price, the amount of sodium polyacrylate they contain, and absorbency?
- What other products contain sodium polyacrylate? What other uses for this product can students generate?
- What are the benefits and drawbacks of disposable and cloth diapers? (A great opportunity to have students scrutinize industry-backed websites and research studies that may not be objective.)
- What is the background of another product you are curious about? What education background does it take to become a chemist or inventor?

These are only a few suggested avenues for further study. After students have become engaged in chemistry through the investigation of sodium polyacrylate, they'll be eager to pursue their own research. ■

References

Bybee, R., and N.M. Landes. 1990. Science for life and living: An elementary school science program from Biological Sciences Curriculum Study. *American Biology Teacher* 52 (2): 92–98.

National Research Council (NRC. 1996. *National science education standards.* Washington, DC: National Academies Press.

Richer Investment Consulting Services. Disposable diaper history. *http://disposablediaper.net/content.asp?2.*

Rohrig, B. 2002. *150 captivating chemistry experiments using household substances.* 2nd ed. Plain City, OH: Fizzbang Science.

Schueller, R. How products are made, volume 3: Disposable diaper. *www.madehow.com/Volume-3/Disposeable-Diaper.html.*

Shakhashiri, B.Z. 1989. C*hemical demonstrations; A handbook for teachers of chemistry.* Vol. 3. Madison, WI: University of Wisconsin Press.

Ellen Schiller (*schillee@gvsu.edu*) is an associate professor in the College of Education at Grand Valley State University in Grand Rapids, Michigan. ***Ellen Yezierski*** is an associate professor of chemistry at Grand Valley State University in Allendale, Michigan.