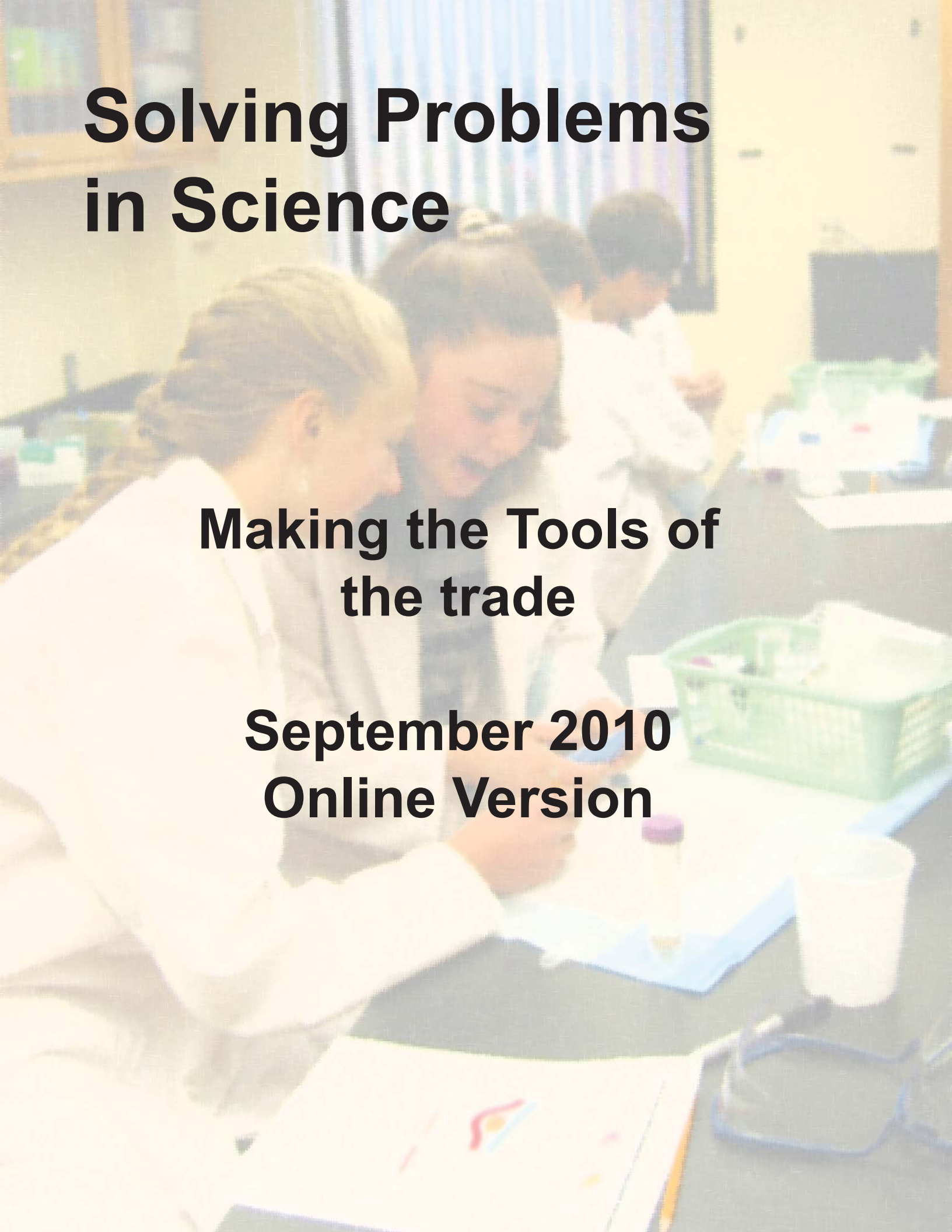
Solving Problems in Science



Making the Tools of the trade

September 2010
Online Version

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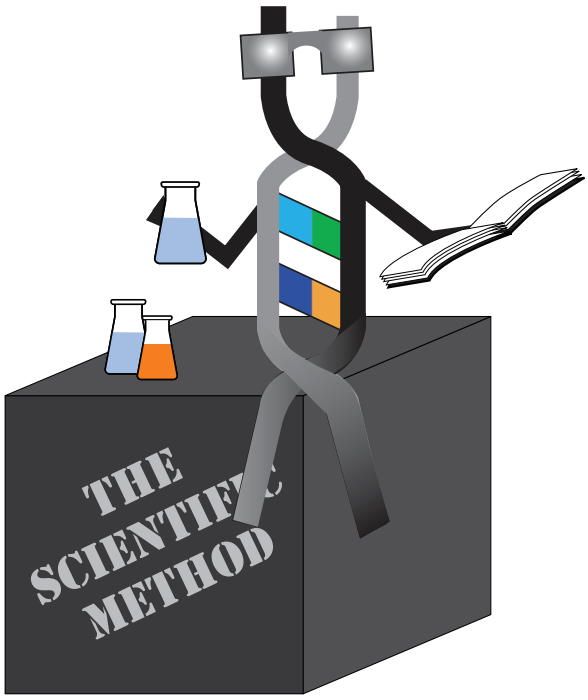
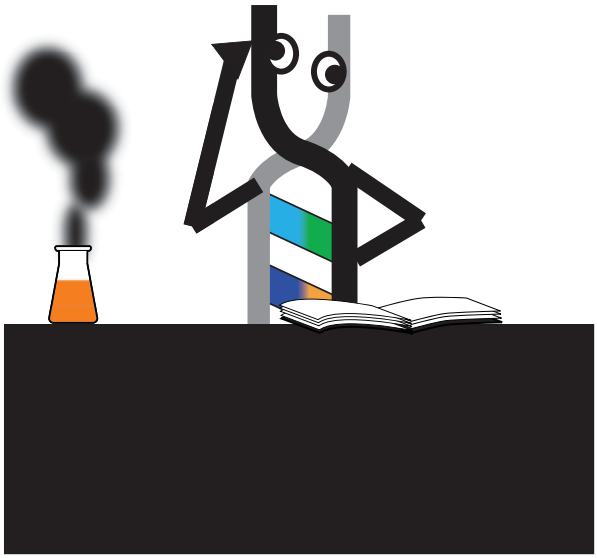
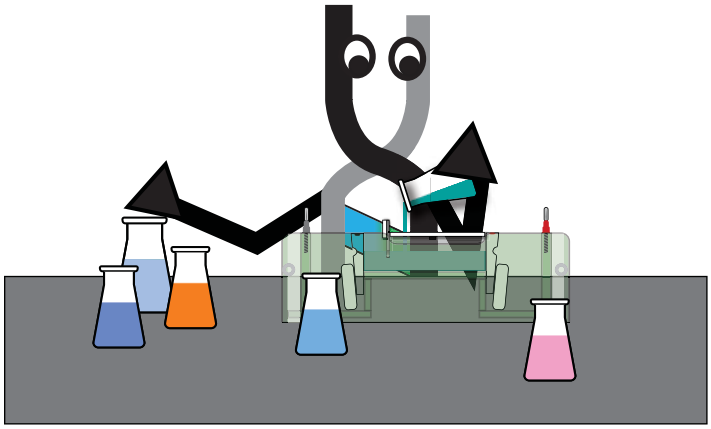


Lighten up, be creative, think outside of the box
Scientists aren't all white lab coats and scientific method. Some really neat science is done by mistake, when people are playing around...um, I mean experimenting.



Know what you know and don't know. You know?
Scientists don't know everything. And if they tell you they do, be suspicious! To solve problems, a good scientists uses her knowledge, and when she comes up against something she doesn't understand, she finds out more; either by reading, or by experimenting!



Get into it!
Play with stuff. Try things out. AKA do science.

No, Seriously, This is How to Use This book:

The Life Sciences Learning Center at the University of Rochester has been involved in developing science curriculum since the early 1990's. One of our goals is to lay scientific research open to young minds, and expose the fun and excitement, as well as convey scientific concepts and principles. This book was developed in collaboration with Dr. Lisa DeLouise, with funding from the National Science Foundation. It is one of our first forays into a more lighthearted piece of curriculum as well as into the realm of physical science. This book has five parts, each of which contains four sub-parts. Each part starts with teacher notes (the blue pages) that explain what the activity is about, objectives for students, materials and potential protocols for students. It also contains a section called "What happens in a classroom" which contains notes from pilot teachers as well as pictures of students doing the activities. In the second part, "What's your problem," a research problem is stated, and students use their creativity and ingenuity to solve it. All these activities are fairly open ended, and invite extension, discussion, thinking...science! The third part, "So what happened" is a brief discussion of what the students might have seen, and what it means. The fourth part "Science Talks," features an interview with a scientist at the University of Rochester whose work relates to the larger problem presented in this book - creating a "lab on a chip."

We envisioned that instructors would photocopy pages out of this book and give them to students. Therefore, the lab notebook is only one page long. Not really how long a lab notebook for these activities should be, but you can copy as many of the lined page as you want, or have students keep their own lab notebook in a spiral notebook or other journal. This book should also come with a CD containing PDF images of each of the student pages (All the pages except for this one and the teacher notes) in case you want to print color copies.

We hope you enjoy this book, and invite you to give feedback and suggestions to us at LSLC_media@urmc.rochester.edu. I personally think that science IS fun and exciting, and one of the neatest things about research is that you play with what you know and what you don't know, and come up with something that no one has known or done before you. It's hard work, no doubt, but great fun. When you use the activities in this book, I hope you appreciate that creativity is an important part of science, that sometimes there isn't just one answer to a question, and that "problem solving" isn't just a "problem," it can be fun and exciting as well.

Shaw-Ree Chen
Author, Editor, and Trouble-Maker
Ph.D. Biochemistry, University of Washington 2003
Messing about the Life Sciences Learning Center since 2004

Shaw-Ree, demonstrating the effects of the diving response on heart rate to LSLC summer camp students.

For more info on the Life Sciences Learning Center, and other free downloadable lessons and media, go to http://lifesciences.envmed.rochester.edu

Tools of the Trade

What is a tool of the trade? Imagine trying to cut hair without scissors, or build a car without a welding iron, or cook dinner without a stove. Tools of the trade help people to do things, and they're very important -- so important that sometimes a tool of the trade can change the way things are done. In this book, you'll learn about efforts to make a "lab on a chip." These devices are small enough to hold in your hand and ship all over the world. You don't need a laboratory to test for disease if you have one of these devices. On a chip that can be two inches square, you might be able to determine what drugs can be used to treat a particular type of cancer, or identify a bacteria that is causing an epidemic. A tool like this could definitely change the way we look at how health care is given.

Scientific discoveries are rarely made by just one person working alone. Throughout this book, you'll learn about the different types of science and scientists whose work goes into making a tool of the trade.

I want to be able to create a "lab on a chip." This device will sort out cancer cells from normal cells, culture the cancer cells in a lifelike environment, allow us to expose the cells to different drugs, and then determine how the drugs affect the cancer cell. All on one device that can be held in the palm of your hand.

How can we capture cells?

I study how small structures, called microbubbles, can be made to best capture and culture cells.

What materials should we use?

I study how to make materials so that they can do interesting things. Depending on how a material is made, it can have different properties. It can conduct electricity, let air pass through, or encourage cellular growth.

How will we "diagnose" what is happening to cells?

Cells themselves are nanosized, and the materials that are used to manipulate them are often just as small. I study how to make and design nanosized materials that can mark and target cells.

Making the Tools of the Trade: A Historical Look at Problem Solving
TEACHER NOTES

WHAT IS IT ABOUT?

This activity engages students in a creative process in which they design a method of separating DNA strands on the basis of length. If students already know about electrophoresis, they're liable to head down that path, but if they do not, then a number of other creative ideas could emerge. The goal here is to talk about different ways of solving problems in science. Although electrophoresis is a tool of the trade, it's worth talking about how other ideas might work or not work as well.

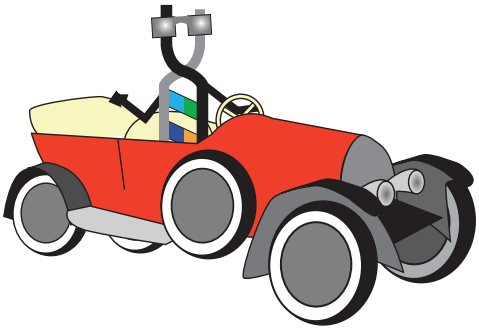
OBJECTIVES FOR STUDENTS:

- **Be creative and use their knowledge to solve the problem presented.**

MATERIALS

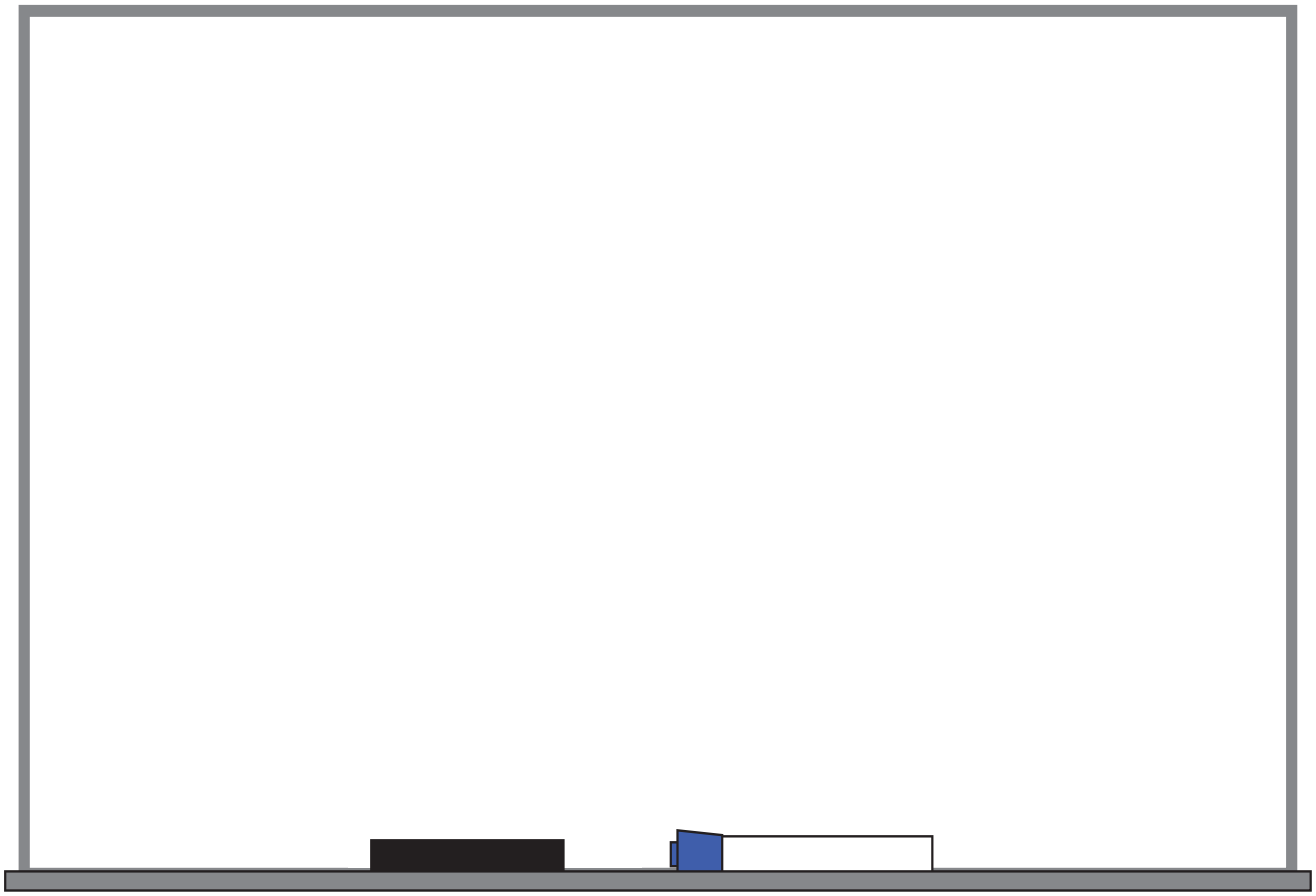
This activity was originally conceived as a brainstorming activity alone, but you could provide different materials for students to be more hands on with. For example, different sized pieces of yarn. If you wanted to get really creative, you could provide them with magnets and magnetic items of different length.

Making the Tools of the Trade: A Historical Look at Problem Solving
What's your problem?

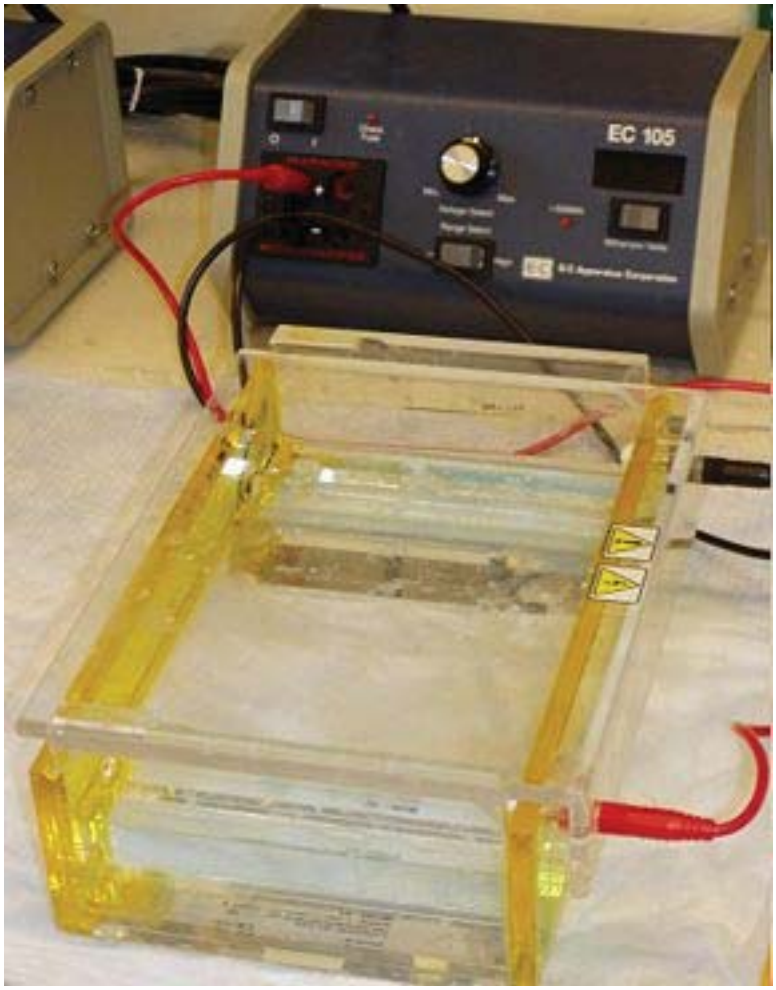


Imagine a crazy scenario. You are living in the 1920's. You just had a brilliant idea that DNA is the genetic material that codes for proteins that make up your body and perform all its functions. You suspect that certain diseases that seem to pop up in families, grandmother to mother to daughter, may represent mistakes in the DNA code. You wonder if you can see differences in sizes of the DNA between someone with a disease and without. How will you do that?

Now remember, you don't have all the tools that you have right now. The scientist next door is separating DNA using gravity (large pieces sink faster than small ones). It takes FOREVER. You want a better way. You know that DNA has a net negative charge and you know you can see it if you apply a DNA stain. But how will you use this knowledge to develop an easy way to separate DNA? You think about what you know about DNA, your experience in separating things of different lengths (ever try to separate out long noodles from short ones?) and you brainstorm…



Making the Tools of the Trade: A Historical Look at Problem Solving
So what happened?



What did your creation look like? Did it look anything like this (See left)? Why is it that almost all gel electrophoresis tanks look like this? Didn't anyone have any more creative ideas for how to do this? Why this chamber? Why this thickness for the gel? Why this length? Why this width? Why a square well and not a round one? Most of us don't ask these questions – we just use it and are thankful that it works! And it's an incredible tool. Without gel electrophoresis units like these, it would take a really long time to do DNA fingerprinting, identify genetic diseases, or do genetic engineering. But somewhere along the line, people had to come up with the idea for how to separate pieces of DNA, and then try a bunch of different things to see what would work best (See pg 9 for an interview with the man credited with coming up with the idea for gel electrophoresis).

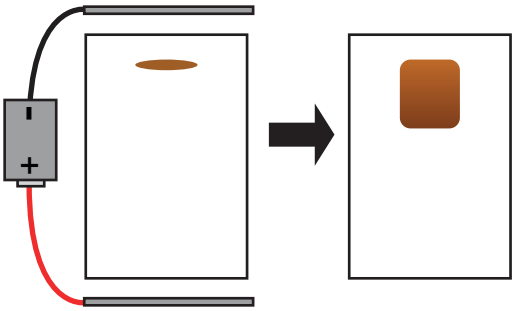
This still happens today – as scientific knowledge progresses, so must the tools that are used to study things. You may have a great idea – say you are studying chemotherapies for cancer. You know that there are many different types of chemotherapies, and many different types of cancer cells, even within a single tumor. You wish there was a way to study large quantities of chemotherapies on many different types of cells, without it taking many many years. How do you DO that?

Making the Tools of the Trade: A Historical Look at Problem Solving Science Talks

An Interview with Oliver Smithies, the man credited with formalizing gel electrophoresis as a scientific technique

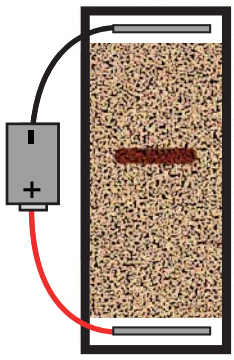
Although Smithies first used this technique to separate proteins of different sizes, his idea to create the gel as a matrix through which things moved and separated was the start of DNA gel electrophoresis. Dr. Smithies was trying to develop a method to detect a precursor of insulin and he came up with something even more interesting!
(for the full interview, see http://www.laskerfoundation.org/awards/2001_b_interview_smithies.htm)

Smithies: I had a problem with the insulin...it wouldn't migrate in my electrophoresis medium, the medium I used to separate proteins, which was filter paper soaked with a buffer. You put the protein on this filter paper and pass it in an electric current. It should migrate down the filter paper and separate from other things. But insulin stuck to the paper, terribly stuck to the paper, and it would just unroll like a carpet. So if you had a small amount it would unroll to here, if you had more it would unroll to here. And it was hopeless.

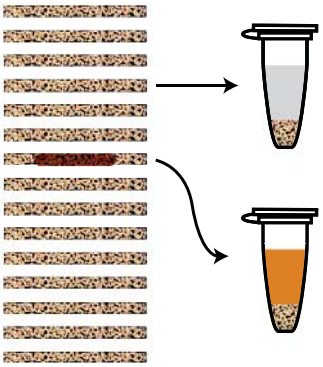


Instead of separating insulin from other proteins, this method smeared insulin on the filter paper

Then I heard of some guys who in the Hospital for Sick Children were using starch grains for a supporting medium for electrophoresis. And to give you an idea of what that's like, it's like taking a sand pie and filling it full of sea water so it's sort of semi-solid, but there really is liquid in it and your protein can migrate all around the different grains and separate. Well they were doing this with starch grains and they had no problems with things sticking to the starch grains. But in order to find the proteins, they had to cut this sand pie, if you like, or this starch block into 50 chunks and measure the protein in each chunk.



In the starch grains, the proteins would separate, but you can't stain the proteins because if you added stain the proteins would get washed away



To figure out where the proteins are, you have to divide up the starch grains, separate the starch from the proteins in solution, and measure the protein in each piece.

That meant 50 protein determinations to do just one electrophoresis. Well, I didn't even have a dishwasher, I didn't have a technician, I couldn't afford anything like that if I was going to do science, but I thought this was neat that it didn't stick to starch

Then I remembered a key thing, and this is part of my history that all of this work stems from in a way: I remembered helping my mother to do the laundry when I was about 12, and when she starched my father's clothes she made the starch by boiling water and whatever. And then after you tied it up at the end it was a jelly, and I thought well, if I just cook the starch into a jelly, then I won't have to slice it like this and I can stain it. And so I can cut out all this 50 protein determinations...and so it was a lazy man's approach, and it invented this new method of electrophoresis that proved to be quite powerful.

Making the Tools of the Trade: Problem Solving
TEACHER NOTES

WHAT IS IT ABOUT?

This activity engages students in a creative process in which they design a method of capturing “cells” and washing them without losing the cells in the process.

OBJECTIVES FOR STUDENTS:

- **Be creative**
- **Keep careful notes on how they made their devices and how to use them**

MATERIALS (Quantities listed per group of 2 students)

50mL Cells:

- Glitter (the very small, “pixie dust” kind of glitter – circles are better than squares)
- Water
- Dishwashing soap

Mix together a half teaspoon of glitter with 50mL water. Add a tiny bit of soap (less than a drop, you can just get a glob of soap onto a toothpick and mix it in) to help the glitter “go into solution” (i.e., sink down into the water).

Materials to make cell capture devices:

- A transfer pipette to flow the "cells" over the device
- A block of modeling clay (if you buy the Crayola modeling clay, you can give each student between ½ and ¼ of the bar of clay)
- A surface to make device on (and to prevent the cell solution from getting all over the place)
  - A large plastic weigh boat, Petri dish works, or even a flat bottom plastic bowl works!
- Whatever items they need to use to shape their devices
  - You can limit them to things they have in front of them, or provide toothpicks and glue sticks to act as rolling pins.

POSSIBLE PROTOCOL

Students should come up with their own protocols in this activity

INSTRUCTIONAL IDEAS:

Have students come up with ideas and keep notes. Then have students trade protocols and see if the other group can duplicate their idea with a fresh block of clay. This often reveals errors or missing pieces of protocols.

Talk about flow rate of media. Sometimes, if you flow the media over the captured cells too quickly, they pop out. Ask students to consider how to mimic the physiological flow rate of blood.

RELATED LESSONS FROM *CONCEPTS AND CHALLENGES IN PHYSICAL SCIENCE*

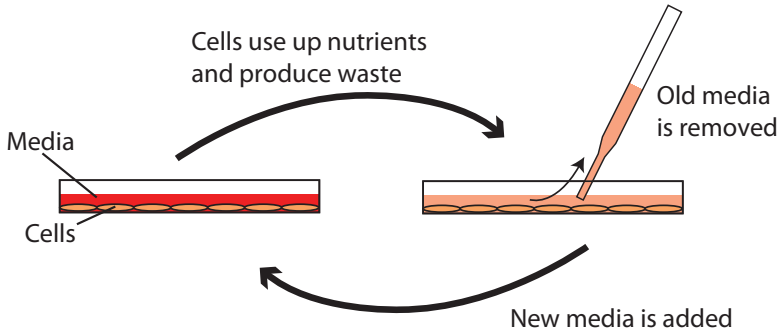
What are science skills?
What is the scientific method?

WHAT HAPPENS IN A CLASSROOM?

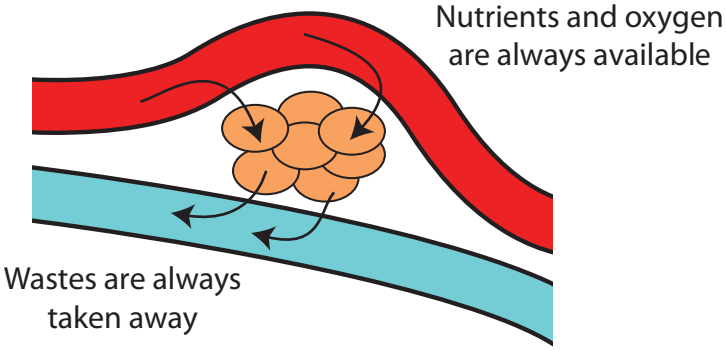
Making the Tools of the Trade: Problem Solving
What's your problem?

Dear Investigators,

We are looking for a tool that will help us to test different concentrations and types of chemotherapy drugs on cells in culture. The problem with our set up right now is that we grow cells in a dish of culture media (A liquid that contains the nutrients that helps the cells grow) and then we replace the media after the nutrients are gone.

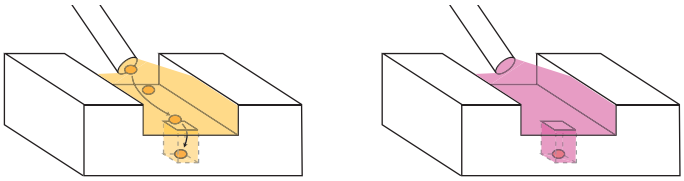


Our set up isn't really how cells live in the human body. In the human body, cells are constantly receiving a flow of nutrients and having wastes removed.



Here's what we'd like you to do: Design a setup where we can flow cells over some wells. We want the cells to be captured somehow, and then be able to pass liquid over the cells without the cells washing out. After you do this, we can work with you on flowing drugs at different concentrations and types over the cells! Our people tried something like this...but the cells kept popping out.

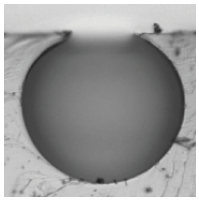
Have to be able to get the cells in by passing liquid over



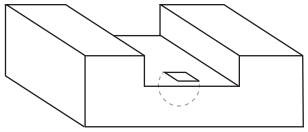
Need to be able to change the media by passing liquid over

Making the Tools of the Trade: Problem Solving
What happened?

What kind of shapes did you make to be able to capture cells? Did it look anything like this?



Cross section of a round well



If so, then neat! This is the shape that Dr. Lisa DeLouise and colleagues found worked at collecting cells and keeping them there.

If yours didn't look like this -- it's still neat! This is because your design may work as well. When Dr. DeLouise came up with this shape, she actually wasn't trying to make it. It was a bit of an accident, as you can read about in the next activity. But once she made it and it worked, she focused on perfecting this shape, instead of trying other shapes. There may be many different ways of capturing and culturing cells. If someone comes up with a design that's different, but works over and over again, no matter who does it -- that's the first step of making a tool of the trade.

What do I want to do when I get older?

How much school do I need?

CAREER BOX: Bioengineering

Bioengineers (also called biomedical engineers) use their engineering knowledge to meet medical needs. Those working in the bioengineering field are working with living systems and applying advanced technology to the complex problems of medicine and biology.

Being a biomedical engineer, you may be called upon to design medical instruments and devices such as magnetic resonance imaging (MRI), the heart pacemaker, kidney dialysis and the heart-lung machine. In addition, you may need to carry out research to acquire new knowledge needed to solve new medical problems.

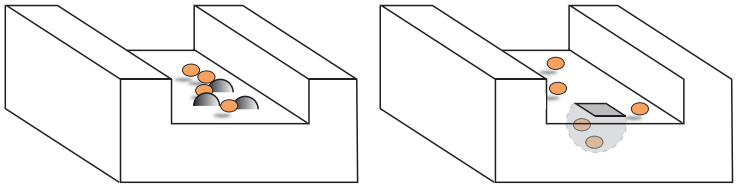
Doctors, nurses and physicians are among your working partners if you work as a biomedical engineer in hospitals or any medical service centers. You need to work closely with them as a team to solve a wide range of challenges. If you work in a laboratory in industry or any research center, you will work along with life scientists, chemists, and medical scientists, to develop and evaluate systems and products for use in the fields of biology and health; such as artificial organs instrumentation, medical information systems, and health management and care delivery systems.

The biomedical engineering student should first plan to become a good engineer who then learns about life sciences. In college, students can major in biomedical engineering, while others may major in chemical, electrical, or mechanical engineering with a specialty in biomedical engineering.

Making the Tools of the Trade: Problem Solving
Science Talks with Dr. Lisa DeLouise (Assistant Professor in The University of Rochester Medical Center's Department of Dermatology and Biomedical Engineering)

A collaborator, Mike King at Cornell University, was trying to separate stem cells from other cells. Stem cells are very special cells, and in a blood sample, there may only be one blood stem cell in a million other cells. Dr. King was trying to take advantage of small differences on the surface of the stem cells to separate them. He designed a method to run cells through a channel. The channel was lined with chemicals that made different kinds of cells flow through at different speeds. The problem was, it wasn't as efficient as he hoped. We thought we could improve on it by slowing cells down as they went through the channel.

We knew from our research that making bumps might result in slowing cells down so much that the channel might get clogged. So another solution might be to catch the cells you want in compartments, like these bubble wells. By catching cells in bubbles, we would get the cells we want and keep the channel free flowing.



The Steps of Problem Solving

Identify the problem	Cells go too fast through the channel so they don't separate as well as they could
Gather Information	Other people have seen speed bumps result in cells backing up and clogging a channel.
State a hypothesis	Try making bubbles
Design an experiment	Make structures (bubbles) to catch cells
Make observations and record data	Bubbles seem to work to catch the cells!
Organize and analyze data	Not only do bubbles catch cells, but the cells actually grow in three dimensions in the bubble shape, just like real clusters of cells.
State a conclusion	Bubbles are a good way of capturing and culturing cells. But maybe we can improve on the process by changing the size or depth of the bubbles and adding other features.

In academics I prefer not to think of my work as "problem solving" but rather the act of "discovery". For example, we conduct experiments to discover the causes of disease, or to create new tools that can help others do breakthrough research. The discovery process also benefits from taking time to think about your goals and to find out what is already known. This way, when you do get around to doing an experiment, the experiment will be well planned, and the results will be new and interesting. To me, scientific discovery is a rewarding experience that is especially motivating when it can benefit human health and society.

Making the Tools of the Trade: It's a gas
TEACHER NOTES

WHAT IS IT ABOUT?

To build on the last section, students have to consider whether it is feasible to hand-construct a tool of the trade every time someone wants to use it. Here, the "manufacturing" concept comes into play. Dr. DeLouise manufactured her devices using a mold. Although she was originally manufacturing pillars, an accident (Really, that's how it happened!) resulted in her manufacturing bubbles that she realized could be used to capture cells.

In this activity, students explore the properties of gas, and how they contributed to making the bubbles.

OBJECTIVES FOR STUDENTS:

- **Understand that temperature changes the volume of a gas**
- **Higher temperatures result in expansion of gas**
- **Lower temperatures result in the contraction of gas**

MATERIALS (Quantities listed per group of 2 students)

- 2mL Saturated Borax solution
  Make using 1 Tablespoon of borax in ½ cup water
- 10mL Diluted Elmer's Glue
  50/50 Elmer's glue in water. You MUST use Elmer's glue…not craft glue
- 1/8th of a Flexible 96 well PVC plate: Order from VWR, catalog number # 62406-241
  Basically, you need something with relatively small holes that you can layer some silly-putty like material over. Most 96 well plates work, but these are inexpensive and can be cut into eighths.

POSSIBLE PROTOCOL

Students can come up with ideas themselves, but this one works:

1. Make up "Polydimethylsiloxane (PDMS)" by mixing 10mL 50% Elmer's glue and 2mL saturated borax solution
2. Spread the "PDMS" in a thin layer over the 96 well plate
   The thinner the layer, the more obvious the expansion of the gas, as the thin layer will bubble up. If the layer is too think, it won't be possible to see the bubble from the top of the "PDMS"
3. Float the plate in different temperature waters. In hot water, the "PDMS" layer will bubble up. In cold water, the "PDMS" will dip down

INSTRUCTIONAL IDEAS:

Incorporate measuring temperature into this process, by having students compare the size of the bubble at hotter temperatures. Students can mix hot and cold water to make the different temperatures.

If students spread a thick layer of "PDMS" over it, they won't see any bubbles – ask them why or why not.

Use the ideal gas law to demonstrate what types of volume changes they might expect to see. Sometimes, students may think they'll see a huge bubble forming, but they shouldn't based on the ideal gas law.

Have students keep careful notes about their manufacturing process. Then in a large group discussion, decide on what procedure worked best. Create a class protocol and have all students try to replicate the process and create identical products. Remind students that having identical products will be important to the experimenter. Discuss the importance of good directions in mass production. (Lisa Brosnick)

RELATED LESSONS FROM *CONCEPTS AND CHALLENGES IN PHYSICAL SCIENCE*

How is temperature measured?
What is pressure?
What is heat?
How is heat measured?
What is temperature?
What is thermal expansion

WHAT HAPPENS IN A CLASSROOM?

From Lisa Brosnick of North Collins, NY

Students were very interested in making the PDMS. Their excitement made them very motivated to experiment with it. Use three different water temperatures (or more if you like) so that students can have a better grasp on the PV=nRT discussion. I found that giving students room temperature water allowed them to grasp the idea of "n" in the equation better.

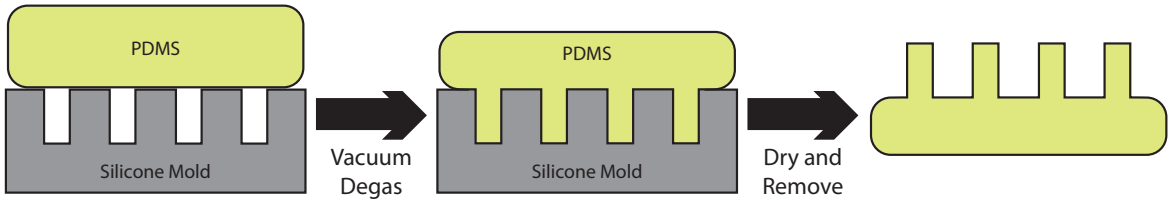
Weaker students had difficulty reasoning through what was expected of them. They needed more guidance. I made an index card with the following:

1) First prepare PDMS according to the directions
2) Create an environment similar to the one Dr. DeLouise was working with when she made her mistake (PDMS on the well tray)
3) Remember she heated the tray. Put yours in a hot water bath
4) Experiment with other temperatures

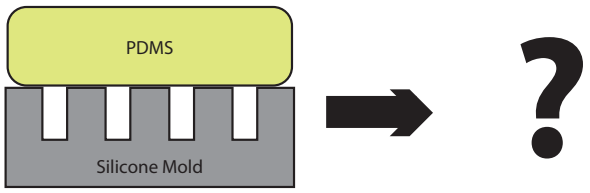
Our students loved this activity. We used it with our 8th grade students as an after exam activity. The 8th grade teacher will use it next year as a review activity before the exam because she was so happy with the results...most students were able to jump into the activity and were very surprised to see the PDMS expand over the wells. They were very interested in the discussion of PV=nRT because of this.

Making the Tools of the Trade: It's a gas
What's your problem?

Dr. DeLouise was not trying to capture and culture cells when she started sculpting plastics into tiny, strange shapes. "We were originally trying to mold bumps." These pillars were supposed to act as speed bumps to cells to slow them down. To make the pillars, she started with a mold made of hard silicone. Then she poured a thick, gooey substance called PDMS onto the mold. The holes in the mold were so small that in order to draw the gooey substance into the holes, she had to put the whole thing into a vacuum, which pulled out the air and drew the PDMS into the holes. Then she let the PDMS dry and pulled it off. Voila! A series of pillars 10-100 times thinner than the hairs on your head.



One day Dr. DeLouise, distracted by other important scientific thoughts (or perhaps thinking of what to do for the weekend), forgot to apply the vacuum step. She put the whole set up onto a warm surface to let the PDMS harden. What do you think happened? Explain why you think this. Perform an experiment that would prove this.



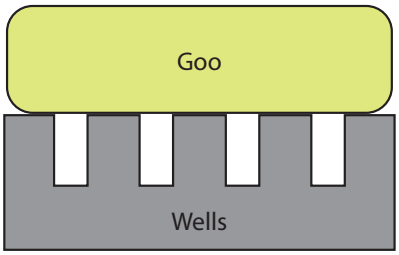
Making PDMS
In a small plastic tray, use a toothpick to mix 10mL of diluted Elmer's Glue with 2mL saturated Borax solution.

What do you think happened when Dr. DeLouise forgot to apply a vacuum?

How will you test your hypothesis?

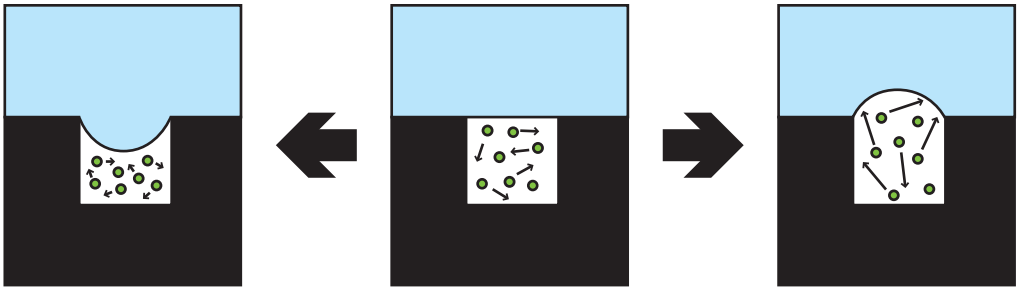
What did you observe?

Making the Tools of the Trade: It's a gas
What happened?



Pouring a thick substance over small wells usually results in the thick stuff sitting on top of the wells, in the wells, there is air. Air is a gas that is made up of about 99% oxygen and nitrogen molecules (O_2 and N_2). These molecules of oxygen and nitrogen are far apart from each other, and moving quickly. When you heat up the air in the well, the molecules speed up even more, and move farther apart from each other, they need more room! This "expansion" of gas pushes the thick stuff up, creating a bubble.

When you cool the air in the wells down, the oxygen and nitrogen molecules slow down, and they get closer to each other and make more room. This "compression" of gas makes room for the thick stuff to sink down, creating a depression.



Math Moment

There are other ways of changing the size of the bubble besides the temperature of the gas. When you pour goop over wells, there are actually a lot of FORCES at work. There is the force of the goop pushing down with gravity.

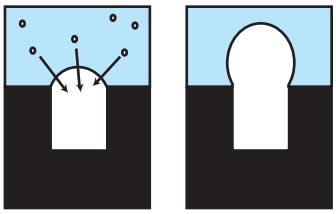
Force = mass (kg) X gravity (9.8m/s2)

But wait! The force of the goop isn't all applied to the well, it's spread out over a large area...so we can't use the total force of the goop. We have to figure out the force in a small area. How will you do that? Assume you weighed out 5 grams of goop. Then the goop was spread even over six wells.

The diameter of the wells is 1cm. Can you figure out how much force the goop is exerting on the gas in the well? What happens to the force if you make the diameter of the wells 10cm?

Making the Tools of the Trade: It's a gas
Science Talks with Ut-Binh Giang, Graduate Student (2006)

When we first made the microbubbles were weren't sure if we could reproducibly make them over and over again and control their size. We knew it had to do with the expansion of gas in heat – when we put the set up at room temperature, no bubbles form. So we wanted to know if we could modify the size of the bubbles by changing the temperature. So, we tested some different temperatures – we put the set up at 65, 75, 90 and 100 degrees Celsius. We predicted that higher temperatures would form larger bubbles. What we found was that there was a big jump in bubble size when we went from 65 to 75 degrees, but after that, 90 and 100 degrees didn't seem to make the bubble any bigger. What we did notice was that gas expansion alone couldn't account for the size of the bubble. If we calculate the volume of air inside the well, and then use the ideal gas law to calculate new volume at a different temperature, the bubbles shouldn't be as big as they were. They were 5 to 50 times bigger than the calculated change in volume. What we suspected was happening was that there was gas dissolved in the Polydimethylsiloxane (PDMS), and when the bubble first formed from the expansion of air, it must then grab the dissolved gas from the PDMS and make the bubble bigger. We tested that hypothesis by degassing the PDMS and pouring it onto the wells. When we did that, the bubbles weren't as big.



Expansion of Gases

Gases expand when they are heated and contract when they are cooled.

As the volume of the gas increases, its density decreases. As the volume of the air decreases, its density increases.

Ideal Gas Law

pV = nRT

p = pressure
V = volume
n = moles of gas
R = gas constant (8.314472 JK−1mol−1)
T = absolute temperature

Gases are all around us, and they affect the properties of everything we work with. Whenever we make something out of materials there are gases in them. When we're making really big things, a little extra gas may not matter. But when we're working on a microscopic level, a little extra gas makes a big difference. We need to know about all the gases that are present and how they behave. For example, if we use regular air, which is 21 percent nitrogen and 78 percent oxygen, we get a certain size bubble. But if we use helium, then we make really small bubbles because helium doesn't dissolve well in the PDMS. Without knowing about what gases are present and where (like in the PDMS and the well) and what other gases we can use, we might have been stuck trying to change the size of the bubble with just temperature alone and not been able make very subtle and small changes.

Making the Tools of the Trade: It's all in the ingredients
TEACHER NOTES

WHAT IS IT ABOUT?

As a continuation of the previous activity, students have just realized that they can make bubbles using the properties of gas, a concoction of "PDMS" and wells. But they have to make sure the properties of the PDMS will work for the types of experiments for which people will be using their tool. The two properties they are concerned with are density and permeability to gases. The students will have to think about how they would make the PDMS more dense? An equally important concept is "how will they determine whether or not the material they make IS more dense?" They will also have to consider how to test whether or not the material is permeable to a gas (in this case, oxygen).

OBJECTIVES FOR STUDENTS:

- **Understand that the properties of matter are dependent on the ingredients of the matter**
- **Understand the density is mass divided by volume**
- **Know how to determine the density of an irregularly shaped object**

MATERIALS (Quantities listed per group of 2 students)

For changing density

- 10mL saturated Borax solution
  1 tablespoon of Borax in ½ cup water
- 40mL diluted Elmer's Glue
  50/50 Elmer's glue in water. You MUST use Elmer's glue…not craft glue
- Anything else the students can think of
  Or you can provide fillers like flour, sand or sugar)
- Small graduated cylinder (50 or 100mL cylinder)
- A wooden stick (To push the material into water to check for displacement
- A calculator

For permeability to oxygen

- Birthday candles (or any small candle)
- Erlenmeyer flask (or any small glass container with a narrow opening)
- Something to light the candle with (long matches, or a long lighter)
- A blob of clay to hold the candle in the flask

POSSIBLE PROTOCOL

For changing density

1) Determine the density of "PDMS" blobs

- Determine mass: Students can weigh a blob of PDMS
- Determine volume: Students should use displacement of water in a graduated cylinder to check for density. To do this, they immerse the blob they just weight into a graduated cylinder full of water (They will have to push the blob into the water, but make sure they don't add in the volume of whatever they're using to push the blob). Record how much water was displaced.

POSSIBLE PROTOCOL (Cont...)

1) Change the density of the material
    - You can alter are the ratios of glue and borax, but students can also add fillers like cornstarch or sand. Sand will actually change the density slightly
2) Measure the density of the new material, as before

For determining permeability to oxygen
Have students come up with different ideas, but this is an easy one:

1) Stick a short birthday candle into a flask with a blob of modeling clay. It should be short enough that the flame doesn't burn what you put across the opening of the flask (1/3 of a birthday candle for a 250mL flask)
2) Take your new "PDMS" material and stretch it into a layer over the opening of the flask.
3) Observe what happens to the candle. Compare it to something that is not permeable to oxygen, like saran wrap, or something that is permeable to oxygen, like a net.

*The goop is not really that permeable to oxygen. It is probably slightly permeable to oxygen, but it will put the flame out. You can either discuss how things can be permeable to oxygen, but not permeable ENOUGH to provide enough oxygen for a flame. Or, you can go with the observation that it is not that permeable to oxygen, and discuss how they might make it more porous"

INSTRUCTIONAL IDEAS:

Teachers should determine the density of their large blob of PDMS. They should then divide the large piece into three smaller pieces and determine the density of each piece again. This will help work through a common misconception that cutting up something will change its density. This also helps them in their experimental procedure because they have three pieces with which to experiment.

RELATED LESSONS FROM *CONCEPTS AND CHALLENGES IN PHYSICAL SCIENCE*

What is the scientific method?
What are the properties of matter?
What are physical and chemical changes?
How are compounds and mixtures different?
What are covalent bonds?
What is conservation of matter?
What is a synthesis reaction?

WHAT HAPPENS IN A CLASSROOM?

From Lisa Brosnick of North Collins, NY

Students are eager to make PDMS again! Slow them down and review how to determine density. Discuss why you may want to mass the object before finding volume. Have students keep careful records of how much each compound they added so their procedure could be replicated if necessary

We found this activity most useful in clearing up misconceptions held by our eighth graders. They were excited to play with the PDMS but were reviewing and practicing critical skills along the way. We did not have time to do the O2 permeability step and just omitted it. This step would have taken another class period because we had them determine density four times. However, this is such an important concept, we decided to really focus on it.

Making the Tools of the Trade: It's all in the ingredients
What's your problem?

Dear Investigators,

The bubbles you made are great, but they're a little too soft. The cells tend to sink into them and if we're not really careful, the material tears really easily. Do you think you could make the material more dense?

Also, one of the things we want to be able to do is to make sure the material allows certain gases to pass through. If we culture a cancer cell in the bubble, we want to be able to sense if the cells are releasing Nitric Oxide (NO). We know from other research that if cancer cells release NO, it means they're dying. So eventually we want to embed a NO sensor beneath the bubbles. But, we have to make sure the material you're using is permeable to NO, that it allows NO to pass through it. For the purposes of your testing, anything that allows oxygen to pass should also allow NO to pass.

How will you determine the density of the material?

How will you increase the density of the material?

How will you determine if the material is permeable to oxygen?

Making the Tools of the Trade: It's all in the ingredients
What happened?

The physical and chemical properties of matter all depend on what the stuff is made of. MATTER is anything that has mass and occupies space. Like the goop. The goop you made is a combination of Elmer's Glue and Borax solution. Take a look at the Elmer's glue and Borax solution. Each has it's own kind of physical and chemical properties. Then when you mix them together, you get a whole new set of physical and chemical properties. This is because mixing them together created a chemical reaction that created a different kind of matter.

Elmer's glue is a polymer of polyvinyl acetate. Polymers are strings of molecules, kind of like the beads on a necklace. When the polymer chemically reacts with Borax molecules, the Borax molecules can link two polymers together, making a new, bigger polymer molecule. When this keeps happening, you get a big blob of polymers that has new physical and chemical properties. Changing the amounts of each ingredient, or adding different ingredients, can change the physical and chemical properties of the goop, like it's density.

What do I want to do when I get older?

CAREER BOX: Material Science

"Materials are the stuff from which all things are made, be they mundane household utensils or sophisticated integrated circuits that drive all of our modern technological society" (TMS Career Resource Center, n.d.).

"Materials Science encompasses the study of the structure and properties of any material, as well as using this body of knowledge to create new types of materials, and to tailor the properties of a material for specific uses. The field encompasses the spectrum of materials: metals, ceramics, polymers (plastics), semiconductors, and combinations of materials called composites" (Iowa State University, Department of Materials Science and Engineering 2001).

Materials science heavily relies on physics, chemistry, other engineering fields such as mechanical and electrical engineering. Physical properties of materials are usually the deciding factor in choosing which materials should be used for a particular application. This involves looking at many factors such as: material composition and structure (chemistry), fracture and stress analysis (mechanical engineering), conductivity (electrical engineering), and optical and thermal properties (physics) to name a few. It also involves processing and production methods.

How much school do I need?

Making the Tools of the Trade: It's all in the ingredients
Science Talks with Dr. Matthew Yates (Associate Professor in the University of Rochester's Department of Chemical Engineering)

My group works on making fuel cells. Specifically, the part of the fuel cell that conducts protons. Not to get too detailed about how a fuel cell works, but there's an important part of it that has to move hydrogen ions (H+). This part is a thin membrane of material. The faster it does this, the more electricity you get.

We make the membrane out of a molecule called hydroxyapatite, or HA. This molecule is actually present in your bones and teeth. But we don't grind up bones to get it, we combine calcium and phosphate, and let it crystallize in just the right conditions. We could just jam calcium and phosphate together and heat it up, and make a lump of HA. But instead, because we're interested in making better materials, we combine using a very specific protocol, which makes the HA crystals form in a very specific way. The way we do it, we can make crystals of HA that are all pointing in the same direction. H+ go down the crystal in one direction. If the crystals all point in the direction we want them to go in, they'll move across the membrane faster and we'll get more electricity out of our fuel cell.

Properties of Matter

Properties are characteristics used to describe an object.

Basic Properties of Matter	**Other Properties of Matter**
Mass -- how much matter is it?	Crystal Structure -- how is it made?
Volume -- how big is it?	Conductivity -- does it conduct electricity?
Weight -- how heavy is it?	
Density -- how solid is it, (mass/volume)?	

In order to do work like we do, we have to know about the properties of matter. We didn't know to use HA until we heard from other studies that one of its properties was that H+ could move through it. The neat thing is that we can change its properties depending on how we make it. Think about it this way. If you pick up a block of wood, you can see it has grains going in one direction. If you cut a slice of wood against the grain, its strength is different from if you cut a slice of wood with the grain. We can craft materials to be stronger, or better at moving protons, depending on how we manipulate the matter. But first, we have to know what its properties are. Someone had to find out that HA moved H+. Then, someone found out what direction H+ moved in the crystal. We used that knowledge to build a material that moved H+ faster. Perhaps someday, it will be used to power a car without gasoline.

The other neat thing about what we've done is that by coming up with a way of growing these fine layers of HA crystals, we've actually helped improve a biological problem as well. It turns out that HA encourages bone cells to grow. So it's used in bone implants. But HA by itself is very brittle. If you have a broken bone, you can't plug it up with HA, it would just break again. You can coat metal, like titanium, with HA, thus giving yourself a strong structure that encourages bone growth and healing. When we came up with our protocol for growing HA crystals, it turned out to be a better way of coating these bone implants as well. So the ideas came around full circle – we used what biologists knew about HA and H+ for our fuel cells, and they used what we found out about how to grow a better layer of HA to make better implants.

Making the Tools of the Trade: Everything changes when you're small
TEACHER NOTES

WHAT IS IT ABOUT?

This section specifically looks at nanoparticles from a surface area perspective. A given mass of small objects has more surface area than the same amount of large objects. From the perspective of making materials, this results in a stronger material. Students can prove this by building bridges (really, blocks that can be used as bridges) out of macro versus micro versus nano-sized particles. They then test the strength of these bridges.

OBJECTIVES FOR STUDENTS:

- Understand that decreased size results in increased surface area for a given mass of objects.
- The more surface area that things have to interact with each other, the stronger the total interaction.

MATERIALS

Students can come up with their own "nano versus macro" sized things. Small dog kibble versus large dog kibble, Big versus little jelly beans, etc About 30g of each item per group. But here's a good, cheap combo that works well:

- Lima beans (macro)
- Mini Lima beans (micro)
- Barley (nano)
- 25mL 50% glue (diluting the glue simply makes it easier to measure)

POSSIBLE PROTOCOL

1. Weigh out 30 grams of each type of building material.
2. Make a rectangular mold for each building material (for the beans, a 2x4 inch rectangular mold works well
3. Pour building materials into each mold (There should be enough to make at least a layer of building materials. If there isn't, you will need to increase the amount of each building material
4. Pour 5mL 50% glue into each mold and mix the glue and the building materials together. Press the building materials and glue down to compress everything together.
5. Allow to dry at least overnight, preferably two nights, as the 50% glue takes longer to dry.
6. Place the bridges between two tables or blocks.
7. Tie a rope or string to a basket, and then hang the basket from the bridge
8. Start adding weights to the basket until the bridge breaks. Record the last amount that the bridge held. Compare this between the bridges.

INSTRUCTIONAL IDEAS:

Have students think of different variables if they are coming up with their own “macro” and “nano” building materials. Should the things be of similar shapes? How much bigger or smaller?

Have students choose proportional items. If nano is 100nM and macro is bigger (Say 500nM) can they find real life objects that are proportional? This requires some math.

The possible protocol above adds the same amount of glue to each bridge. This isn’t REALLY correct. You should add an amount of glue that is proportional to the surface area of the object. Have them calculate how much glue they would have to add if they covered the surface area of large beans versus nano beans with a layer of glue 0.5mm thick. This is a really tough math problem that requires knowing the density of the glue. You can simplify the beans into circles to make the math a little easier.

Have students convert the weights into a measurement of force on the bridge.

RELATED LESSONS FROM *CONCEPTS AND CHALLENGES IN PHYSICAL SCIENCE*

What is force?
What is gravity?
What are balanced and unbalanced forces?

WHAT HAPPENS IN A CLASSROOM?

Making the Tools of the Trade: Everything changes when you're small
What's your problem?

Dear Investigators,

OK, so we're on our way to making these microbubbles out of materials that are the right density, and permeable to nitric oxide! Nearly there!

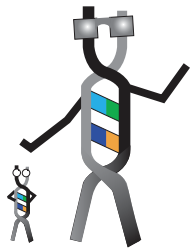
Here's the last thing we need to think about. We have to build a sensor that will tell us when the cells are producing nitric oxide (NO). That way, we'll have a way of capturing cancer cells, passing drug over them, and then all we'll have to do is look at the device and see which cells are dying and producing NO. Pretty neat. But what should we use as a sensor?

I heard about a lab that makes really tiny nano-sized things called "quantum dots" that can glow. Maybe they can make some that glow when there's NO around? People are telling me that it would be great to make these sensors out of nanoparticles, because there's so much surface area in a microgram of particles that we'd be able to detect really small amounts of NO. I wonder how that works? I mean, if they're so SMALL, how can they have so much more surface area?

What happens when you have more surface area in building materials?

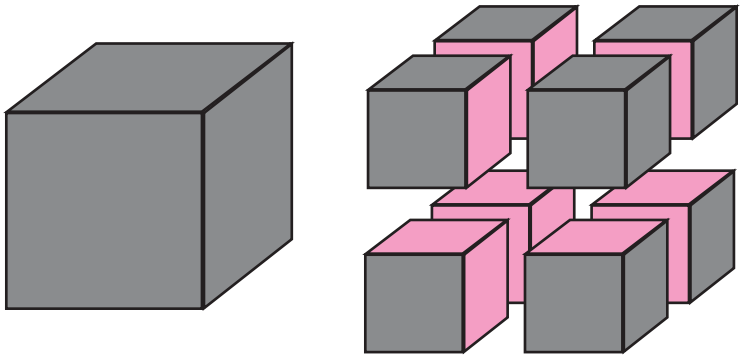
1) Weigh out 30 grams of large, microsized and nanosized building materials.
2) Use tinfoil to make a rectangular mold that will hold each of the three kinds of building materials.
3) Add the same amount of diluted glue to each one and mix the glue and building materials together
4) Allow the blocks to dry overnight.
5) Think about which bridge will be the strongest!
6) The next day, make bridges out of the three blocks and see which ones hold the most weight.
7) What do you observe?

Making the Tools of the Trade: Everything changes when you're small
What happened?



So maybe now you know what the fuss is about nanoparticles -- SURFACE AREA! Nanoparticles have a lot of it. Now, you may be thinking, "wait a minute, if it's smaller, how can it have **more** surface area?" You're right! It's not the surface area of a single particle that's so great…it's the surface area of a bunch of things that have the same weight.

Take this cube for instance. It has a nice gray surface. Now, cut the cube into smaller pieces. Look at all the extra surface area! If this were a piece of cake, and you were concerned about the mass, you wouldn't care if you ate the cake as one piece or as eight pieces. BUT, if the surface of the cake and each of the pieces had frosting, and you LOVED frosting, then those eight pieces would have more frosting, and thus be much tastier.



When you use 30 grams of nanomaterials to make a substance, versus 30 grams of a non-nanomaterial, it tends to be stronger. The reason is all that surface area. Molecules interact with each other on their surfaces. When sheet metal is formed, it's done by melting the metal to spread it out, and then cooling it to allow the atoms to crystallize. A sheet of nickel is actually made up of many "grains" of nickel crystals. These interactions between the grains help to slow down impacts on the metal. If the grains were very small, and had a lot of surface area to interact with each other, the metal would be much stronger for the same amount of weight. Think about making bulletproof armor for soldiers. The lighter and stronger it is, the better.

Math Moment

Let's say you work for a skeptical boss who doesn't want you to use nanoparticles. He says he doesn't think there's that much more surface area at all. How will you prove it?

You have nanospheres, and macrospheres. The nanospheres have a diameter of 50 nanometers. The macrospheres have a diameter of 500 nanometers. They have the same density (.1mg/mm3) because they're made of the same material. How much surface area is present in 1000g of nanospheres? What about 1000g of macrospheres? How can you figure this out?

Making the Tools of the Trade: Everything changes when you're small
Science Talks with Dr. Todd Krauss (Associate Professor in the University of Rochester's Department of Chemistry)

My laboratory works on making nanoparticles that emit light in certain situations. We're interested in making these small particles and understanding how they behave when you shine light on them and put them in different situations. Do they emit bright light? Are they robust particles, or do they break down quickly? If they're stable particles, and they light up when you shine infrared light on them, then they become useful for biologists.

The cellular world exists at the nanometer scale or smaller – proteins, signaling molecules, and the cell itself. So if you're going to try and interact with a cell, tell it to divide, or maybe to kill itself (like you'd want to kill a cancer cell), you've got to work at the nanoscale. Historically when people try to "talk" to cells, they use molecules such as antibodies or small drugs.

Nanoparticles are bigger than small molecules and they're more stable. You don't have to keep a nanoparticle in the fridge, and it can be exposed to air without it breaking down. But because they're small, you can do things like dissolve them in water, which is good if you want to use them to talk to cells in the human body. Nanoparticles have a large surface area compared to their volume. You can actually put a lot of small molecules, like antibodies, on the surface of a nanoparticle. If you do that, you've got a good chance that the nanoparticle that can home in on whatever it is the antibody attaches to.

Scientific Measurements: The Metric System

Prefix	Abbreviation	Meaning
kilo	k	one-thousand
hecto	h	one hundred
deca	da	ten
deci	d	one tenth (one in ten)
centi	c	one in one hundred
milli	m	one in one thousand
micro	μ	one in one million
nano	n	one in one hundred million

We can make nanoparticles called "quantum dots" that emit light. So, if you shine a flashlight on these dots, they'll glow very brightly. They glow much more brightly than the fluorescent dyes that are currently used in biological research. That's great, because we can see the nanoparticles, even when there aren't that many of them.

Here's an example of what biologists can do with our quantum dots: We can make a quantum dot big enough to 8 antibodies that attach to cancer cells, and 100 drug molecules. Now, if you just injected someone with 100 drug molecules, those molecules might go all over the body, and never see the cancer cell before the body got rid of them. But attached to this long-lasting nanoparticle that also has antibodies, the drug now homes in on the cancer cell, and all 100 drug molecules are where they should be. And, we can shine an infrared light on a person, infrared light goes through human tissues, we'd be able to look and see where all the quantum dots went and from that, figure out where the cancer is. Mind you, this is in the future, we're not quite there yet, but we hope to be there soon!

‘s

Lab Notebook

Why do we keep a lab notebook?

1) Organization: It keeps all your thoughts, plans, and results in one place. Why repeat an experiment you’ve already done but forgot about? Or better yet, if you want to repeat an experiment you’ve done well, it’s nice if all your procedures and plans are easy to find.
2) To get rich: OK, that may be a stretch, but what if you find out something that’s really exciting and other people care about (or would pay you money for)? You have to be able to prove you did it, and show exactly how you did it so that other people can repeat it on a larger scale. If you have a great idea, but can’t tell someone how to do it, or prove that you did it before someone else, all it will ever be is an idea.

How to keep a lab notebook

1) Put a date next to all your entries
2) If you make a mistake, draw a thin line through the error, don’t black it out with blobs of ink, or white it out. What if it really wasn’t a mistake?
3) Include detailed procedures so that someone can repeat what you’ve done, without you having to explain it while they’re doing it. Sketches are a good way of doing this.
4) Write down notes. If something doesn’t work, make a note as to why you think it doesn’t work, so that the next day, you can improve on it. If it does work, note that it does work so you don’t come back after a vacation and wonder what happened.

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