Small-scale Science

A "small is better" technique that dramatically reduces the quantity of chemicals used in science labs

Photographs by Alan Slater

by Alan Slater

Subject areas: science, environmental studies

Key concepts: environmental awareness, safety, green chemistry

Skills: microscience techniques

Location: indoors/outdoors

Materials: microplates and plastic pipettes

I was a research and development chemist in the petrochemical industry just when concerns about pollution began to arise. A common attitude then was that "the solution to pollution is dilution." Dump the offending material into the landfill, river or air and forget about it. We all did this in our daily lives, too — paints and cleaning agents went down the drain, raw sewage ran into the sea. In the science classroom lab, large five-pound (now two-kilogram) bottles of chemicals were "used up" each year. Many of us can probably remember a science class when a large spill occurred or some apparatus exploded. Then, at the end of the period, it was all washed down the sink or put into the garbage.

In the good old days, we would allot at least $600 per course for lab materials in our high school. Now we have a hard time spending $100 for the 1,000 science students who use the chemicals and related equipment in our courses. This is because we now do most of our experiments on a small (micro) scale. Microscale science is the most exciting, innovative technique I have seen in over 30 years of teaching science and chemistry, and it is sweeping the globe. Using a drop of solution no bigger than this small dot • and grains of solid the size of this dash —, we can get the same lab results as in the past, while reducing the quantity of materials we use by at least 10 times and often 100 times or more.

Although microscience has the most impact in chemistry classes, it has applications in general science and biology classes and wherever chemicals are used. It addresses issues of pollution, waste disposal, lab safety and our attitudes toward the environment, yet at the same time maintains the "hands on" experience and saves time for both the teacher and student. Everyone, including the environment, is a winner!

Combination reaction well plate designed for high school use.

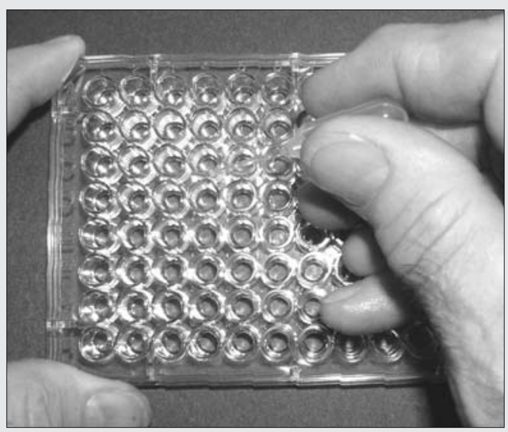
Equipment

About 20 years ago in the United States a group of very creative teachers saw the latest plastic technology used in medical labs and envisioned the potential uses of this simple plasticware in chemistry. Only two very basic pieces of equipment are needed to start with: a well plate and a pipette. Although both are regarded as disposable in the medical field, they can be reused many times in school. Some well plates have been in service for over 10 years; and while pipettes do not usually last that long, they are made of recyclable plastic.

Sizing up Microscale Science

To micro-size means:

Increased safety, because small quantities of chemicals (0.02 milliliters of solution or 1–2 grains of solid) are used and students have more control over a reaction.



Less waste, because such small quantities are used that waste and disposal is minimized.

Less storage space needed for materials, as only small amounts need to be stored, whether as solutions or in solid form. A solution for a whole class can be stored in one micropipette. The classroom chemical inventory will be reduced by at least 90 percent, and probably much more.

Less breakage, because the basic equipment is plastic and quite durable.

Money saved on chemicals and equipment. A well plate can last ten years or so, and a 500-gram bottle of chemical could last 1,000 years or more.

Faster cleanup and much less water used in washing up.

Less distilled water needed, thus saving both the cooling water and the energy used in distilling.

Time saved in doing experiments and, as a result, many students want to, and do, repeat lab experiments. Instead of cleaning up and rushing on to another class, students have time within the same period for post-lab reflections and for entering and manipulating numerical data on a computer spreadsheet. More time can be spent on designing experiments and developing higher order thinking skills.

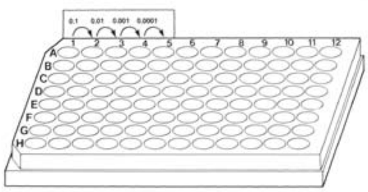
Time saved by the teacher in preparing for a class, as only small quantities of materials are needed and there is very little equipment to move around. For example, one can carry all the solutions for about ten labs in one small tote box.

What are the drawbacks? Very few, but...

- You need a good electronic balance reading to 0.001 grams for high school quantitative work. If not, you must make either more highly concentrated solutions or larger volumes of stock solutions.
- As with any new method, new techniques must be learned.

Producing and collecting gas in a well plate.

Easy setup demonstrates electrolysis using only 5 ml of solution.



The most common **well plate** in use is the 96-well plate, which is equivalent to 96 test tubes. There are also 24- and 6-well plates, as well as combination reaction plates designed specifically for use in high school science. Combination reaction (or dual well) plates consist of half of a 96-well plate (i.e., 48 small wells) and half of a 24-well plate (i.e., 12 larger wells), and some are made of a plastic that is resistant to organic chemicals. Each well on a 96-well plate can hold about 0.3 milliliters of solution (12–16 microdrops), and the rows and columns are labeled. The 24-well plate replaces beakers in most experiments, with each well having a volume of less than 4 milliliters.

Well plates are typically made of polystyrene, which is very durable and easy to clean. Stubborn stains can be removed with cotton swabs and water (most organic solvents should be avoided except on the organic-resistant comboplates). As polystyrene is non-wetting, dilution procedures and cleaning can be done quickly and effectively. Stirring can be done using toothpicks or plastic stirrers. Typically, the plates cost two to six dollars each.

The **pipettes** are made of polyethylene and can be purchased to dispense as many as 50 drops per milliliter. Thus a single drop can be as small as 0.020 milliliter, or 0.020 grams. Often one drop is all that is needed for an experiment in which 10 milliliters or more might have been used before. The pipettes are non-wetting and easily cleaned, and can deliver very accurate drops when handled correctly. They can also be cut to make a variety of other pieces of equipment, such as the simple distillation apparatus described below. There are four types of pipettes normally used. In bulk, these cost five to eight cents each.

Experiments

With these two very simple pieces of equipment — a well plate and a pipette — students can easily do a whole range of experiments, such as testing the density of liquids, solubility curves of a solute such as potassium nitrate, chromatography of water soluble inks, collecting and testing various common gases, electrolysis of various ionic solutions and fuel cells, and testing foods for proteins. Here are some brief examples:

- White solids from the supermarket can be analyzed and unknowns determined.
- Any gas can be produced and collected safely and quickly with a well plate, a one-hole stopper and a graduated pipette (see photo). For example, oxygen can be made from a well-known bleach, hydrogen peroxide, using a simple mineral, pyrolusite rock. This is a catalyst and can be is reused many times. The oxygen can even be tested with a glowing toothpick! Even hydrogen/oxygen mixtures can be exploded safely with this apparatus.
- Electrolysis of many solutions can be done in 5 to 10 minutes with 5 milliliters of solution (see photo). A similar apparatus, using graphite electrodes, can electrolyse a magnesium sulphate solution (Epsom salts) to make hydrogen and oxygen. Disconnecting the battery and using a multimeter can show a fuel cell with a voltage around 2 volts. The cost is only about $5.
- Two graduated pipettes can be cut up and, with a

syringe plug and plastic T, made into a simple distillation apparatus that can be used in a hot water bath.

• For labs involving the dilution or neutralization of solutions (e.g., acid/base), the numerical scale across the top of the well plate is ideal for use as a scale of concentration or pH. One creative Grade 12 student used a 96-well plate and pipettes to determine the relative amount of active ingredient present in various consumer products such as aspirin, juice or wine.

When I first tried this new method, I used an old semi-micro lab and scaled it down from big drops to one small drop. The results were just as good but quicker and easier for the students to do. Then I began asking myself, "Why do I use so much? Can I use 10 or even 100 times less?" In almost every case, the answer was a resounding yes. Where I previously used 10 milliliters of a solution and a graduated cylinder, I could use 0.1 milliliter (5 drops) dispensed from a small pipette — a 99 percent reduction in chemical use. Even labs that could not be done in a well plate could still be scaled down by at least 10 times. A reaction using 200 milliliters was simply modified to use 20 milliliters and done in a smaller container. Where I once used 50 liters of distilled water for a lab, I now needed only 5 liters. With about $100 worth of plasticware and a questioning mind, I could reduce our chemical use by 90 to 99 percent! This meant my chemical waste was also reduced by 90 to 99 percent. My old two-kilogram bottles and even my 500-gram bottles have now become dinosaurs.

Students in the lab are constantly exposed to ways of reducing their use of materials. In fact, it is often a game to see who can do a reaction with the minimum number of drops. If there is a spill, it is usually no more than one milliliter — hardly a horrible mess to clean up — and it provides an example of reduction at the source. How easy is it to clean this up in our lab compared to dealing with it at the sewage plant or cleaning it up later downstream.

Except for a final rinse of the plates or pipettes, students put no waste materials down the sink. What little waste is generated has been reduced further by constantly finding new processes that use up this waste. For example, waste copper solutions can be saved and the copper ions later removed by adding scrap iron (iron nail in the lab).

My students have enthusiastically embraced this new way of doing labs. They are not alone: through my involvement in microscience techniques, I have presented workshops across North America, England and Africa. There is global interest in this, and certainly many uses of small-scale science in developing countries where science education might otherwise go down the road we traveled many years ago.

Our biggest problem in the classroom now is sewage gas! There is so little cleanup water going down our drains that the traps are in danger of drying out and thus letting the sewer gas back into the lab.

Alan Slater *is a retired science/chemistry teacher who has given workshops across North America and England on microchemistry and microscience and received a number of awards for his work in this area. He is co-author, with Geoff Rayner-Canham, of* Microscale Chemistry *(Addison-Wesley, 1994), a microchemistry lab manual and teacher's guide for high school chemistry. He lives in St. Mary's, Ontario.*

Supplies

Canada

Boreal Northwest <www.boreal.com>, search on "microchemistry." A good source of microchemistry kits, equipment and lab manuals.

United States

Educational Innovations <www.teachersource.com>, search on "microscale" for a list of well plates and pipettes available.

Kemtec Educational Products <www.kemtecscience.com/Chemistry.htm>, see Microchemistry section under "Chemistry Kits."

Flinn Scientific. PO Box 219, Batavia, IL 60510-0219, 1-800-452-1261, flinn@flinnsci.com, <www.flinnsci.com>. Best source of equipment and lab books in the U.S. Their catalog has a wealth of ideas.