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The key to understanding and explaining the physical world around us is observation. The recent study "Vegetation Communities of Ledges State Park, Boone County, Iowa" (Johnson-Groh, 1985) is largely observation. On the other extreme, even the most theoretical research done with paper, pencil and computer must be compared with *observations* of that which it hopes to explain. The first step in doing science, or studying science, is to observe.

People have been observing the world around them for centuries. Most often this observation is casual in nature and is insufficient to promote understanding. When asked to describe a passing car, a casual observer may respond that it was a small, red car. A more careful observer might tell us that the car was a red, 1978 Ford Pinto hatchback, rusted, quite dirty and burning oil. This critical observation allows us to understand something about the car which the more casual one does not. To understand any aspect of our world requires observations. The deeper our current understanding, the more detailed our theories become, and the more detailed our observations must be as well.

This has not always been the prevailing view. The Greek philosophers of 500-300 B.C. believed that "reality" should be explored by pure reason rather than by critical observation, and most certainly not by experiment (physical labor). Sometimes the only link between the physical world and the ancient Greek understanding of it was casual observation. Around 350 B.C., Aristotle may have made the casual observation that stones fell faster than leaves. He then "reasoned" that

> . . . the heavier an object was, the more eagerly it would strive to achieve its proper place, since the heaviness was a manifestation of its eagerness to return [to the earth]. Hence a heavier object would fall more rapidly than a lighter one.

This incorrect view was to last nineteen centuries until Galileo considered the matter (Asimov, 1982).

Galileo, generally considered the father of experimental science, was a critical observer, and more importantly, he was among the first to test his observation and theories by experiment. Galileo may have observed that the wind could blow leaves but not stones, and concluded that the wind, as well as an object's weight, could affect the speed of its fall. (His exact reasoning process is, of course, unknown.) In any event Galileo decided to test Aristotle's conclusion by observing the fall of two objects ". . . upon whom the wind could not act." It is said that he dropped two cannon balls of different weights from the leaning tower of Pisa, and observed that they fell at the same rate. Galileo concluded that air resistance slowed the fall of light objects of relatively large surface area. Objects that were heavy and compact enough to make the air resistance negligible, fall at the same rate. Galileo conjectured that in the absence of air *all* objects would fall at the same rate. (A good vacuum could not be produced in his day, but when a vacuum was finally produced, Galileo was proven correct.) (Asimov, 1982).

Over the past few years, I have had the pleasure to speak to several groups of junior high and high school youth about science. I always try to convey something of the nature of science as a process of discovery. To this end I have devised a series of interactive exercises which can be used as demonstrations or experiments dealing directly with the scientific process of discovery.

Demonstrations

When I talk of the importance of observation I usually start with this story about Aristotle and Galileo, although stories about Lavosier and the conservation of mass, Newton and the law of gravity (Asimov, 1982) and many others would also work. I then proceed with a few simple observation exercises. The first exercise demonstrates just how poor our casual observation usually is. By prearrangement, someone, usually the teacher, leaves the room while I am discussing Galileo. I then ask the class what this person was wearing. Usually a class can recall most of the person's attire, but only with some discussion. The person is then asked to return, and we see how good our observation, and recall, have been. A few questions, "How many of your remembered correctly the color of the shirt/blouse, shoes, etc.?" illustrate the point.

Two chemical demonstrations serve to introduce indirect observation and to allow the students' egos to recover by making more careful observations. The first demonstration involves hydrolysis of *t*-butylchloride. This demonstration stimulates more careful observation. The second is the blue bottle demonstration which provides an entry point into indirect observation and deduction (Summerlin, 1985).

In the hydrolysis demonstration, a bottle of colored liquid is prepared according to the directions given at the end of this article. It is placed on the table and the students are asked to describe it. Their description is written on the board. The students are told that something about this bottle will change. Anyone who sees a change is asked to raise his or her hand, and inform us of the change. (The liquid undergoes a series of color changes over about 30 minutes.) Typically a good natured competition ensues to see who will be the next to see a change, thereby fostering observation.

In the blue bottle demonstration a stoppered bottle partially filled with a colorless liquid is held up before the group. (Directions for preparation of this bottle are also given later in this article.) The ground rule is that the bottle cannot be opened or broken. The question: what is in the bottle? Several guesses are usually made without justification. When pressed for justification, the group will usually conclude that the bottle must be opened to determine what is inside. When asked why it must be opened, they may respond "so we can see/smell/taste/feel the liquid." At this point I discuss the difference between direct and indirect observation. (This discussion and a useful exercise will be presented in another paper.) Because the bottle may not be opened, the class must rely on indirect observations to identify the liquid.

The bottle is then passed around the room. A few questions are asked to facilitate indirect observation: (a) Could it be milk? (b) Could it be mineral oil (baby oil)? (c) Could it be corn syrup? Why or why not? (None of these possibilities are correct. (a) It is clear and colorless. (b) It does not leave an oily film on the bottle. (c) It is not thick (viscous) enough.) By this time, or by prompting with the question "Could it be soap?" someone will have shaken the bottle turning the liquid blue. While the meaning of this is being considered, the color will fade to colorlessness.

At this point the question changes to "Why does the color change?" Considerable detailed information is available to a sophisticated observer of this demonstration, including the general nature of the process leading to the color change. However I find it advantageous to halt the discussion, give the answers and discuss how they might be obtained by indirect observation.

Preparation of Materials

t-Butylchloride Hydrolysis

To about 225 mL of water in a 250 mL bottle, add 4mL of universal indicator (Fisher SI60-500) and 0.5-1 mL of *t*-butylchloride (2-chloropropane available from Aldrich, C5,635-2, and Fisher at a higher price). Adjust the pH to about 10 (indicator violet) by adding dilute ammonia or sodium hydroxide dropwise. The *t*-butylchloride will slowly hydrolyze

$$(CH_3)_3CC1 + H_20 \longrightarrow (CH_3)_3COH + HC1$$

releasing HC1, lowering the pH and driving the indicator through a series of color changes (Summerlin, 1985).

The rate of this process depends on temperature, the concentration of *t*-butylchloride and the solvent. In water at room temperature using the concentrations indicated above, the entire range of colors will be produced in about 30 minutes. Using 50 percent aqueous isopropanol as suggested in Summerlin, the process will take about 2 minutes. The color sequence can be repeated by adjusting the pH back to 10. The solution may be disposed of by washing down a sink with water.

Blue Bottle

Prepare a solution of 5.7 g of NaOH in 300 mL of water in a 500 mL clear bottle. Cool the solution and add 10 g dextrose (glucose), a small (match head size) amount of solid methylene blue, and tightly stopper the bottle. (Be careful not to add too much methylene blue.) CAUTION: This solution is strongly basic, one of the reasons for the "no opening" ground rule. The solution should clear in a few minutes. Shaking the solution turns it blue. It will fade to colorlessness in one to two minutes. The solution is good for about 15 shakings and should be used within 6 hours. As the dextrose is oxidized (see below) yellow oxidation products build up in solution. The solution, minus the dextrose, can be made up at any time prior to the demonstration. The dextrose should be added a few minutes before the demonstration. The solution may be washed down a sink with plenty of water after use (Summerlin, 1985).

Basic dextrose is a reducing agent which reduces methylene blue to the colorless state. Shaking the bottle dissolves oxygen from the air space above the solution, oxidizing the indicator to the blue state. Within approximately one minute the blue fades as the dissolved oxygen is (indirectly) reduced by the basic dextrose in solution. The reaction occurs in four steps (shown unablanced):

$$O_2 \text{ (gas)} \longrightarrow O_2 \text{ (dissolved)}$$

$$\underset{}{O_2 \text{ (dissolved)}} + \underset{\text{(red. colorless)}}{\text{methylene blue}} \longrightarrow \underset{\text{(ox. blue)}}{\text{methylene blue}} + OH^-$$

$$\text{dextrose} + OH^- \longrightarrow \text{glucoside}$$

$$\text{glucoside} + \underset{\text{(oxidized)}}{\text{methylene blue}} \longrightarrow \underset{\text{(reduced)}}{\text{methylene blue}} + OH^- + \text{gluconic acid}$$

The exact mechanism is far more complex than this. Even the simplifed mechanism above may be too complex for classroom use. A simpler, yet qualitatively correct, description of the color change is: Shaking dissolves oxygen which oxidized the indicator, methylene blue, to its "blue" state. The oxidized indicator is then reduced back to its "colorless" state by the dextrose, a reducing sugar.

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