Scientific data: It's not as pretty as it looks!
By Dave Warner

Teacher background

Learning Standards addressed:
Science as Inquiry
Science in personal and social perspective
History and nature of science

Introduction

This exercise was inspired by research conducted by high school students in John Signorelli's Environmental Studies class at Whitney Point High School. Mr. Signorelli has been teaching his students how to monitor the water quality in Whitney Point reservoir for 5 years. In addition to learning about water quality and its importance, the students post their data on a web site (now in limbo) as part of the Susquehanna River Watch Project. This project includes 10 schools in the Susquehanna basin that monitor water quality each fall and spring. In Mr. Signorelli's class, they use chemical test kits from HACH Company. This exercise was developed because of a discovery made with the nitrate (a form of nitrogen considered to be an important aquatic nutrient) test kit.

While working with this class, we discovered that different people sometimes obtain different nitrate values with the same sample. We saw this as a "teachable moment" and realized that if the data were to be useful, the students would have to investigate the errors involved in using these test kits. We quickly realized that the things learned about measurement with the HACH kits were applicable to many forms of measurement.

Learning objectives for students:
Learn that measurement is often an inexact part of science
Learn and apply the definition of accurate
Learn and apply the definition of bias
Learn and apply the definition of precision
Learn to utilize available information to form hypotheses
Learn to test hypotheses using the HACH test kits

Cornell Environmental Inquiry Research Partnership
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Student background and assignment

Part I.

Most people think of theories (like the big bang) or explanations (evolution) when they think of science. Science as taught in our schoolbooks often seems lifeless and static, and most of all definite. If you look at the definitions below, you will notice that the first definition of science you see is filled with action words like observation and investigation. The reality of science is that it is active and changing, and it is a lot of work!

Science -
1a. The observation, identification, description, experimental investigation, and theoretical explanation of phenomena. **b.** Such activities restricted to a class of natural phenomena. **c.** Such activities applied to an object of inquiry or study.
2. Methodological activity, discipline, or study: *I've got packing a suitcase down to a science.*
3. An activity that appears to require study and method: *the science of purchasing.*
4. Knowledge, especially that gained through experience.

One of the most common things done by scientists is the act of measurement. This descriptive process results in something we call data, which are KEY ingredients in the formulation of ideas, hypotheses, and theories. Measuring can be simple and straightforward like the measurement of fish lengths to complex and confusing, like the measurement of plant responses to different environments.

Another misconception about science is that the data or values we assign to different variables are exact, **accurate**, **unbiased**, and **precise**. If only this were true! In reality, measurements are often only close to the real value, and often the real value is unknown!

MORE DEFINITIONS!!!!!
Accurate – without error, conforming to fact

Precision - (1): the exactness to which a value is specified, more specifically, the number of significant digits with which a number is expressed (2) The degree to which results of repeated identical tests are similar

Bias - (1) **:** deviation of the expected value of a statistical estimate from the quantity it estimates (2) **:** systematic error introduced into sampling or testing by selecting or encouraging one outcome or answer over others

Accuracy and precision are different, and can be demonstrated by the bull's-eyes in Figure 1 and 2.

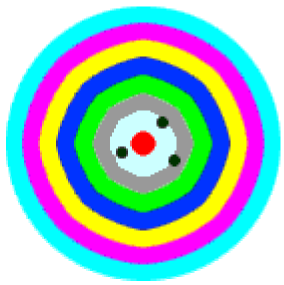

Figure 1. Accuracy

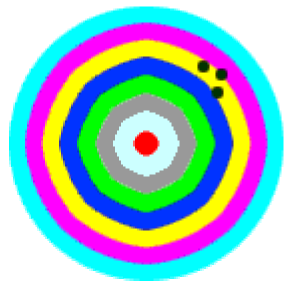

Figure 2. Precision

One area where accurate data are essential is water quality monitoring. Water quality matters because water is essential to life. Many scientists study this to make sure our water is safe to drink and to look for human impact on water quality. Sometimes water researchers and other scientists are asked to testify about the quality of their data in court or in Congress. Water quality tests often use chemistry to answer questions about water samples. For example, scientists have found that the amount of algae found in water is related to the amount of nutrients that enter the water. In order to be able to testify in court or otherwise share data, scientists need to be sure that the data are correct to the best of their ability. If there are limitations in the data, those using the data need to know about these limitations.

Your job now is to use the definitions above to determine if several chemical test kits used to measure the amount of nitrate (NO_3^-) in a water sample are accurate, biased, or precise. We will start with a demonstration, so just follow the steps below.

1) Get a 3x5 note card and write a 1, 2, and a 3 on successive rows.
2) At each station with a color wheel test kit, hold the tester above eye-level so you can look through the two windows in the front toward a source of light.
3) Turn the wheel until the color in each window is the same, and record the number from the wheel for each station (1, 2, or 3). Multiply this number by 4.4 and record the new number. This is your nitrate concentration in milligrams per liter (mg/L).

We will then look at a plot of our data. All values recorded for each station are shown as an X, while the true value is shown as a horizontal line.

Did everyone in the class get the same values?
How did these values compare to the actual values?
What are some potential reasons for differences, if any?

Part II.

Now we will start the hard part. You have seen that different people can get different results in the same test, and that there is the potential for error in the tests you have done. What you will have to do for the remainder of this project is use the definitions above, the graph from our demonstration, the test kits and standard solutions, and your knowledge to determine the quality of the results that one gets from the HACH nitrate test kits. You will be graded on whether have answered the questions. You will have to figure out what you need to do to find the answers to these questions.

1) Are the data from the test kits accurate?

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2) How wide is the range of values for a given concentration?

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3) Are your own results biased? If so, are they too high or too low?

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4) Are data from others biased? If so, are they too high or too low?

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5) Are the test kits precise?

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