

# TEACHING “MEASUREMENT” IN SCIENCE

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## SCIENTISTS ALWAYS COLLECT “FACTS” WITHIN THE APPROACH OF SOME THEORY (Losee, 1980, p. 135).

- The scientist invariably interprets experimental findings with the aid of some theory (Duhem).
- Example: “What is of interest to the scientist is not simply that the pointer of some instrument is on 3.5. Such an observation is only of value in conjunction with an interpretation of its meaning. For instance, the pointer reading is interpreted to mean that the current in a circuit is a certain value, that the temperature of a substance has a certain value, or something similar.”
- In other words, “there are no irreducible facts devoid of all theory.”

## THE PARADIGM THEORY DETERMINES HOW THE INSTRUMENTS ARE MADE AND HOW DATA IS COLLECTED (Kuhn, 1970, p. 126)

- “Science does not deal in all possible laboratory manipulations.”
- Scientific operations and measurements are determined by the current paradigm theory.

## EXPERIMENTAL ERROR LEADS TO MULTIPLE POSSIBLE INTERPRETATIONS OF MEASUREMENTS (Losee, 1980, p. 135)

- The scientist recognizes that the instruments he or she employs have a finite experimental error (Duhem).
- Example: “If a manometer is read ‘3.5’, and if its limit of experimental error is  $\pm 0.1$  atmosphere, then any pressure between 3.4 and 3.6 atmospheres is consistent with the reading.”
- “Duhem expressed this by suggesting that indefinitely many ‘theoretical facts’ are consistent with a set of experimentally given conditions.”

## MEASUREMENTS REQUIRE UNITS!

- Measurements include values (numbers) and **UNITS** (dimensions).
- Consistency in the units (dimensions) used in a set of measurements is crucial!  
Example: In 1999 NASA lost a ~\$130 million Mars climate orbiter. Reason: Miscommunication between the climate orbiter spacecraft team and the mission

navigation team. One team was using the metric system of measurement and the other team was using the English system.

### **ACCURACY VS. PRECISION**

- Accuracy is “telling the truth”; precision is telling the same story over and over again (Yiding Wang, yiwang@mtu.edu)
- Accuracy: The closeness of a measurement to the “true” value for a specific physical quantity. It is expressed as either an absolute error or a relative error.
- Precision: How well a measurement can be reproduced.
- Precision: The agreement among several measurements that have been made in the same way.
- Precision: Is limited by the instrument. It is determined by the finest divisions on the instrument’s scale.
- Example: Difference between precision and accuracy: Bullseye diagram.

### **SOME COMMON MISCONCEPTIONS ABOUT MEASUREMENTS**

- Measurements are numbers.
- Measurements are exact values.
- In a student laboratory: “My values are wrong (they don’t exactly fit known numbers for this phenomenon), therefore my experiment didn’t work.”

### **“ERROR” IN SCIENTIFIC MEASUREMENT IS UNCERTAINTY, NOT MISTAKES**

- “Error” does not connote the term mistake.
- “Error” refers to the uncertainty in the measurement.
- You can not eliminate errors, but you can ensure that they are reasonably small relative to your signal.

### **WHAT CAUSES MEASUREMENT “ERRORS”?**

- Instrument errors: Accuracy, range, response time, age of instrument, etc.
- Calibration errors: Models, standards.
- Operator error (human error).
- Measurement location error.

### **TYPES OF ERRORS (UNCERTAINTIES IN MEASUREMENTS)**

- Random error: Any factor that randomly affects measurements of a variable across the sample. This does not affect the average of the measurements.

- Example of random error: For any electrical sensor (that measures temperature, conductivity, or fluorescence), there is uncertainty in the current source and the voltage measurement.
- Systematic error (bias): A factor that systematically affects measurements of a variable across the measurement. This does affect the average of the measurements.

## HOW DO WE REPORT UNCERTAINTIES IN MEASUREMENTS?

1. Measured value of  $X = X_{\text{best}} \pm \delta X$
2. Significant figures: Because  $\delta x$  is an estimate of the uncertainty, it should be reported to the same significant figure as your measurement allows.  
Example: If the temperature that you measure is  $5.6^{\circ}\text{C}$ , it is meaningless to report the uncertainty as  $5.6 \pm 0.1345$ . The uncertainty cannot be known to four significant digits with your measurement!
3. Propagation of Error: Measured values are used to calculate other quantities (e.g., measurements of mass and volume are used to calculate density). Thus the estimation of uncertainty of the calculated quantity (e.g., density) should include the uncertainties in all of the measured quantities (e.g., mass and volume). For quantities calculated from sums, differences, products, or quotients, the uncertainty is the sum of the uncertainties in the measured values.

## USING ANALOGY TO HELP STUDENTS UNDERSTAND UNFAMILIAR UNITS OF MEASURE

Example: Understanding the Unit “Light Year: A “Student Minute” (Smith, 1992, pp. 25-27, “Time Traveler”)

- The light year, ly, is a difficult unit for most students to understand, because a time unit, the year, is being used to measure distance.
- A light year is defined as the distance that light can travel in one year, almost 9,461 trillion kilometers!
- Distances in astronomy are too large to work with easily when expressed in units like meters or kilometers.
- It is very common to express distances in terms of time, like “Jerry’s house is only 15 minutes from my house.”

- Let's now create a "Student Minute," working in groups of 2 or 3. One person should start at one end of the hall and walk **quietly** heel-to-toe in a straight line for exactly one minute. Mark where you start and stop.
- Measure how far the person walks, to the nearest meter.
- Repeat this measurement three more times.
- Calculate the average distance (of the four repeated measurements) the person walks. We will call this distance a "student minute."
- 1.a. Are all "student minutes" the same? 1.b. How are they similar?
- 2.a. How are "student minutes" similar to a light year? 2.b. How are they different?
- 3. How many meters are in three "student minutes"?
- 4. Your residence is 600 meters from your 8:00 am class. If you leave your residence at 7:45 am and are only allowed to walk heel-and-toe, can you make it to class on time based on your "student minute"?

## REFERENCES

- Kuhn, T. S. (1970). The Structure of Scientific Revolutions, 2<sup>nd</sup>. Ed. Chicago: The University of Chicago Press.
- Losee, J. (1980). A Historical Introduction to the Philosophy of Science, 2<sup>nd</sup>. ed. New York: Oxford University Press.
- Smith, P. S. (1992). Project Earth Science: Astronomy. Washington, DC: National Science Teachers Association (NSTA) Publications.