Practices of Science: Scientific Error

NGSS Science and Engineering Practices: Planning and Carrying Out Investigations

When a single measurement is compared to another single measurement of the same thing, the values are usually not identical. Differences between single measurements are due to error. **Errors** are differences between observed values and what is true in nature. Error causes results that are inaccurate or misleading and can misrepresent nature.

Scientifically accepted values are scientists' current best approximations, or descriptions, of nature. As information and technology improves and investigations are refined, repeated, and reinterpreted, scientists' understanding of nature gets closer to describing what actually exists in nature. However, nature is constantly changing. What was the best quality interpretation of nature at one point in time may be different than what the best scientific description is at another point in time.

Errors are not always due to mistakes. There are two types of errors: random and systematic. **Random error** occurs due to chance. There is always some variability when a measurement is made. Random error may be caused by slight fluctuations in an instrument, the environment, or the way a measurement is read, that do not cause the same error every time. In order to address random error, scientists utilized replication. **Replication** is repeating a measurement many times and taking the average.

Systematic error gives measurements that are consistently different from the true value in nature, often due to limitations of either the instruments or the procedure. Systematic error is one form of bias. Many people may think of dishonest researcher behaviors, for example only recording and reporting certain results, when they think of bias. However, it is important to remember that bias can be caused by other factors as well. **Bias** is often caused by instruments that consistently offset the measured value from the true value, like a scale that always reads 5 grams over the real value.

SF Fig. 1.4. Instrumental error occurs when instruments give inaccurate readings, such as a negative mass reading for the apple on a scale. Photo by Alyssa Gundersen

Error cannot be completely eliminated, but it can be reduced by being aware of common sources of error and by using thoughtful, careful methods. Common sources of error include instrumental, environmental, procedural, and human. All of these errors can be either random or systematic depending on how they affect the results.

- **Instrumental error** happens when the instruments being used are inaccurate, such as a balance that does not work (SF Fig. 1.4). A pH meter that reads 0.5 off or a calculator that rounds incorrectly would be sources of instrument error.
- **Environmental error** happens when some factor in the environment, such as an

uncommon event, leads to error. For example, if you are trying to measure the mass of an apple on a scale, and your classroom is windy, the wind may cause the scale to read incorrectly.

- **Procedural error** occurs when different procedures are used to answer the same question and provide slightly different answers. If two people are rounding, and one rounds down and the other rounds up, this is procedural error.
- **Human error** is due to carelessness or to the limitations of human ability. Two types of human error are transcriptional error and estimation error.
    - **Transcriptional error** occurs when data is recorded or written down incorrectly. Examples of this are when a phone number is copied incorrectly or when a number is skipped when typing data into a computerprogram from a data sheet.
    - **Estimation error** can occur when reading measurements on some instruments. For example, when reading a ruler you may read the length of a pencil as being 11.4 centimeters (cm), while your friend may read it as 11.3 cm.

Scientists are careful when they design an experiment or make a measurement to reduce the amount of error that might occur.

Question Set:

1. When estimating the area covered by an object, what type of error might you make and what sources might have caused it? Can you do anything to reduce the amount of error that might occur?

2. What other sources of errors might you need to be aware of when conducting scientific investigations?

3. How can you reduce error when you design experiments or make a measurement?