**Ecological Sampling**

Ecological sampling is the process by which small representative sections of an area are used to estimate the composition, or the properties, of a larger area. The representative sections are called **samples**.

One type of sample is the food samples that are passed out at grocery stores. A store may be trying to convince customers to buy a certain product, like a brand of pizza, by offering bite-sized samples (e.g. Fig. 1). Customers only get to taste the sample, so they have to assume the whole pizza will be like the sample. However, if the pizza has many different toppings, the sample piece may not have all of the pizza toppings. For example, a customer who receives the pizza sample in Fig. 1A would assume that it is from a pepperoni pizza. Another sample (Fig. 1B) would reveal that the pizza also has mushrooms and peppers. Samples C and D would provide even more information (broccoli and olives). By sampling the pizza many times, a customer is more likely to taste a variety of toppings and to be able to more accurately describe the entire pizza.



**A B C D**

Image courtesy of J. Phillippoff

**Fig. 1**. Four samples from the same pizza

The need to analyze multiple samples before making conclusions is important not only in shopping for pizza but also in scientific sampling. In order for estimates to be accurate, samples should be representative of the whole–the whole pizza, the whole population, or the whole area. However, there is no guarantee that any sample will be perfectly representative of the whole. Thus, repeated sampling, or replication, is important.

Sampling is a powerful tool that is important across many scientific disciplines. The type of sample taken depends on the discipline and on the task involved (see Table 1).

**Table 1**. Examples of sampling across scientific disciplines

|  |  |  |  |
| --- | --- | --- | --- |
| **Discipline** | **Study Purpose** | **Specific Task** | **Sample Characteristics** |
| **Medicine** | Determine the overall health of a dog using blood cell types as an indicator | Determine the percentage of each type of blood cell in a dog | Blood draws using sterile needles |
| **Geology** | Determine historical atmospheric carbon dioxide composition using ice layers | Determine the various composition of layers of ice in a large ice sheet | Cores drilled into an ice sheet |
| **Chemistry** | Investigate mercury levels in various aquatic environments over time | Determine levels of mercury in a freshwater lake | Water samples collected at different locations and depths in the lake |
| **Population Ecology** | Look at change in snail population over time to assess changes in population | Determine number of snails on a rocky beach | Count snails in a number of small areas on the beach |
| **Genetics** | Determine if two fish populations that *look* similar are connected or if they are distinct populations | Use genetic analysis to determine if there is a genetic difference between two populations of fish | DNA extracted from fish at each location |

**Activity: Sampling Design**

Sample a bag of colored objects to determine its composition.

**Materials**

* Small colored objects in a bag
* Sampling tool (e.g. spoon)

**Procedure**

1. Write down all of the different colors that are in the bag. If you cannot see into the bag, use your prior knowledge to come up with a list of the possible colors of the objects inside.
2. Make predictions about the colors of objects in the bag.
   1. Which color(s) do you think are most abundant?
   2. Which color(s) do you think are least abundant?
3. Using your predictions, develop and record a hypothesis about the colors of objects in the bag.
4. Each person will be taking a sample of objects from the bag. Develop a standardized sampling scheme considering the following:
   1. How many objects should each person collect?
   2. What will be used to collect the samples?
   3. How will samples be removed from the bag?
   4. How will you ensure that the sampling is random?
   5. What will you do if a person takes a sample that is larger or smaller than the size determined by the class?
5. Using the procedure developed by the class, sample the bag. Each member of the class should take one sample. Complete Table 2 with the colors of objects you sampled, the total number of each color, the total number of all the colors together, the fraction of each color compared to the total, and the percent of each color compared to the total.

**Table 2**. Individual sample data table

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Number** | **Color** | | | | | | **Total** |
|  |  |  |  |  |  |
| **Fraction**  **of Total** |  |  |  |  |  |  |  |
| **Percentage**  **of Total (%)** |  |  |  |  |  |  | **100%** |

1. Based on your individual sample,

a. What can you infer about the colors in the bag?

b. How do you think your sample may compare to other people’s samples?

1. Record three samples from any three class members on a class data table. Table 3 is an example data table; you can modify the number of color columns and rows based on your class.
2. Based on the first three samples shared by the class,
   1. What can you infer about the colors in the bag if data collection stops at this point?
   2. What might you observe as we add more samples to the data table?
3. Record the remaining samples on the class data table. For each color, determine the average, fraction of total, and percentage of total.

**Table 3.** Class colored object sample data table

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Sample Number** | **Color** | | | | | | **Total # of objects sampled** |
| **Red** | **Orange** | **Yellow** | **Green** | **Blue** | **Brown** |
| **1** |  |  |  |  |  |  |  |
| **2** |  |  |  |  |  |  |  |
| **3** |  |  |  |  |  |  |  |
| **4** |  |  |  |  |  |  |  |
| **5** |  |  |  |  |  |  |  |
| **6** |  |  |  |  |  |  |  |
| **7** |  |  |  |  |  |  |  |
| **8** |  |  |  |  |  |  |  |
| **9** |  |  |  |  |  |  |  |
| **10** |  |  |  |  |  |  |  |
| **11** |  |  |  |  |  |  |  |
| **12** |  |  |  |  |  |  |  |
| **13** |  |  |  |  |  |  |  |
| **14** |  |  |  |  |  |  |  |
| **15** |  |  |  |  |  |  |  |
| **Total** |  |  |  |  |  |  |  |
| **Average** |  |  |  |  |  |  |  |
| **Fraction**  **of Total** |  |  |  |  |  |  |  |
| **Percentage**  **of Total (%)** |  |  |  |  |  |  | **100%** |

**Activity Questions**

1. What did you learn about the composition of the bag by collecting data on your individual sample?
2. What did you learn about the composition of the bag by compiling and averaging class data?
3. How did your individual data, the first three points of class data, and the entire set of class data compare? Explain.
4. Ask your teacher to share the known proportion of each color of object in the bag. How did the averaged class data proportion of colors compare to the known proportion of colors? Explain why you think this occurred.
5. What would result in your sample data if you picked your favorite colors out of the bag when sampling?
6. What situations in nature might cause individual samples not to reflect the larger area?
7. What would happen to your sample data if there were just one or two objects of a particular color in the bag?
8. What are the sources of error in this sampling activity? How well do you think your sampling procedure controlled for bias? Explain.
9. How do you think this activity accurately represented sampling in a real environment, like the intertidal?
10. How do you think this activity was different from sampling in a real environment, like the intertidal?

Practices of Science: **Scientific** **Error**

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 repeat a measurement many times and take the average. This is called **replication**.

**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.

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 computer program 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.

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**SF Fig. 1.4.** Instrumental error occurs when instruments (such as a scale) give inaccurate readings, such as a negative mass reading for the apple in the above figure.

**Special Feature Questions**

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?

Practices of Science: **Precision vs. Accuracy**

Precision and accuracy are two ways that scientists think about error. **Accuracy** refers to how close a measurement is to the true or accepted value. **Precision** refers to how close measurements of the same item are to each other. Precision is independent of accuracy. That means it is possible to be very precise but not very accurate, and it is also possible to be accurate without being precise. The best quality scientific observations are both accurate and precise.

A classic way of demonstrating the difference between precision and accuracy is with a dartboard. Think of the bulls-eye (center) of a dartboard as the true value. The closer darts land to the bulls-eye, the more accurate they are.

* If the darts are neither close to the bulls-eye, nor close to each other, there is neither accuracy, nor precision (SF Fig. 1.5 A).
* If all of the darts land very close together, but far from the bulls-eye, there is precision, but not accuracy (SF Fig. 1.5 B).
* If the darts are all about an equal distance from and spaced equally around the bulls-eye there is mathematical accuracy because the average of the darts is in the bulls-eye. This represents data that is accurate, but not precise (SF Fig. 1.5 C). However, if you were actually playing darts this would not count as a bulls-eye!
* If the darts land close to the bulls-eye and close together, there is both accuracy and precision (SF Fig. 1.5 D).

|  |  |  |  |
| --- | --- | --- | --- |
| **A** | **B** | **C** | **D** |

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**SF Fig. 1.5.** Dartboards showing different accuracy and precision scenarios

**Special Feature Questions**

1. An oceanographer needs to go out in a boat to retrieve an important temperature and salinity data logger that is attached to an underwater stake on a coral reef. How does each of the following situations illustrate the differences between precision and accuracy?
   1. The oceanographer checks the weather forecast the night before her trip so she knows what to wear on the boat. The TV forecaster says it will be between 26 and 31 degrees (°) Celsius (C) at noon the next day. The actual temperature reading the next day on the boat at noon is 28° C.
   2. When the oceanographer’s Global Positioning System (GPS) indicates that she is at the location of the stake, she anchors the boat and jumps in the water to collect the data logger. However, she can’t find the stake. The other GPS units belonging to her colleagues on the boat also indicate that they are at the correct location. After an extensive search, the oceanographer finds the stake 50 meters (m) from the boat.
   3. While on the way back to shore, the oceanographer throws in a fishing line to see if she can catch anything for dinner. She is lucky enough to catch a mahi-mahi. When she pulls it out of the water, her colleagues estimate the weight of the fish. Their estimates are 16.1 kilograms (kg), 16.8 kg, and 15.9 kg. When they weigh the fish upon returning to shore, the actual weight is 18.2 kg.
2. Write your own scenario illustrating the difference between accuracy and precision. Swap your scenario with a classmate. Identify your classmate’s scenario measurements as accurate or inaccurate and precise or imprecise.
3. A dart player can see how accurate his or her dart throws are by comparing the location of the thrown darts to the target, the bulls-eye of the dartboard.
   1. How is this model different from scientists who are measuring a natural phenomenon?
   2. Is there a way for scientists to determine how accurate their measurements are? Explain your answer