



How To Achieve Scientific Quality Data

GLOBE		Related SDGS	Type of Activity
Sphere	Protocols		
Atmosphere	All	4 (Quality Education) 13 (Climate Action)	Exploratory

Overview

Scientific measurements require certain conditions in both the procedure and the instruments used to obtain quality and scientifically valid data. In addition, prior practice of measurements in the classroom is required before making a field trip to take real data.

Time

1 lesson of 80 minutes

Prerequisites

None

School Level

Secondary

Purpose

To teach students that, in order for research data to have scientific value, they must be obtained following certain procedural criteria, which reduce the percentage of error to a minimum.

Student outcomes

- To explain the concept of calibration
- To deepen the concepts of accuracy, precision and the types and sources of error.
- To describe what a protocol is and the importance of following the established step-by-step procedure to achieve scientifically valuable data
- To understand the importance of instrument care and correct use for proper maintenance and conservation and to make the data usable.

- To promote students' critical thinking that translates into the ability to solve problems in and out of the classroom.

Introduction

When dealing with scientific data, it is essential to handle the most precise and accurate data we can, so that the percentage of error is minimal or zero and we are able to obtain quality research.

Precision and **accuracy** are two measures used in scientific studies to determine the **percentage of error**.

Precision is the detail with which an instrument or procedure can measure a variable while accuracy is how close this measurement is to the actual value. For example, if a person is weighed on the same scale every time, it will be accurate even if it is not his/her actual weight, but if he/she is weighed on different scales, it will be difficult to keep track of his/her actual weight because each scale will have a percentage error.

It is possible for a system to be highly precise, but not accurate, and vice versa. One way to represent the difference between precision and accuracy is with a dart board. If the center of the dartboard is the true value, the closer the darts are to the dartboard, the more accurate they will be, and the closer the darts are to each other, the more precise they will be (see Fig. 1).

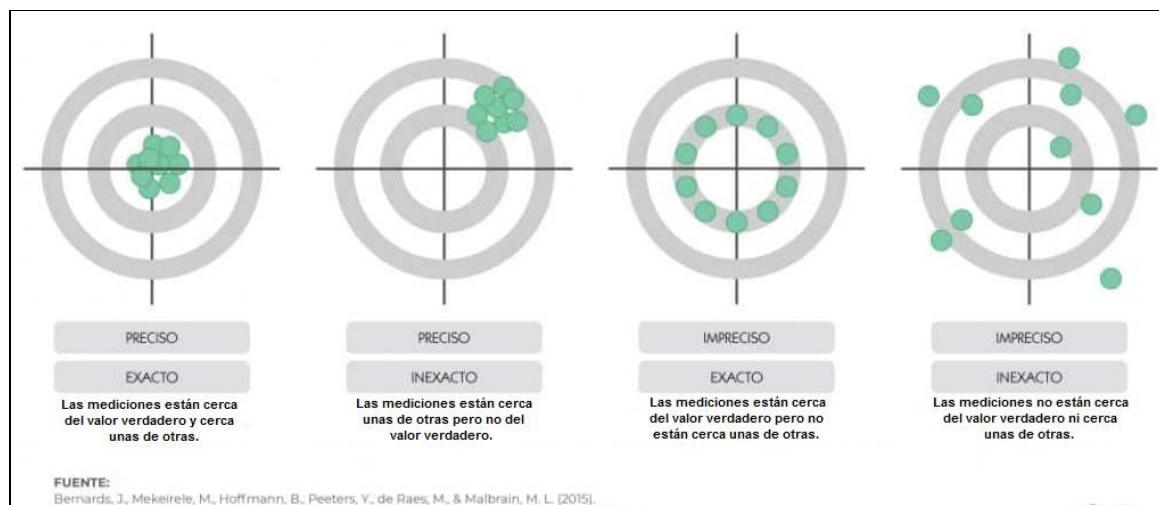


Fig. 1: Precision and accuracy

The measurement of variables always involves some degree of error. No method provides a measurement that corresponds 100% with reality. The *error* is the difference between the actual value and the measured value. However, since the actual value is never really known, the error must always be estimated.

In scientific research, two main errors are recognized, random error and systematic error.

Random error refers to the random difference between the observed and true values. It is a natural error, since there is always some variability in the measurements: fluctuations in the environment, the instrument or the interpretations themselves. The random error is known as "noise" because it blurs the true value of what is being measured. Keeping random error low will allow accurate data to be collected.



Systematic error or "bias" is the proportional difference between the observed and true values of something.

This is an error in the design or analysis of the study that produces an incorrect or invalid estimate of the method under study. An example of a systematic error is a poorly calibrated scale that constantly registers higher weights than they really are.

A systematic error affects the accuracy of a measurement, i.e. how close the observed value is to the true value.

Knowing what the source of error is will allow us to reduce its incidence and identify if our measurement is accurate and precise.

How is the error percentage calculated?

The word error just means an error or a deviation from what is expected. There is a way to quantify exactly what percentage error there is in a measurement. This is called percent error and is a ratio of the difference between the actual value of your measurement and the true value. This ratio is then multiplied by 100 to convert it to a percentage. A percentage error of less than 10% is acceptable (<https://estudyando.com/medicaciones-cientificas-exactitud-precision-y-porcentaje-de-error/>).

It is calculated with the following formula:

$$\% \text{ error} = \frac{\text{Medición} - \text{Valor real}}{\text{Valor real}} \times 100$$

Example of an error calculation in temperature measurement:

$$\% \text{ error} = \frac{16^{\circ}\text{C} - 17^{\circ}\text{C}}{17^{\circ}\text{C}} \times 100 = 5,88\%$$

Whether the measurement is greater than the actual value or the actual value is greater than the measurements, the percent error must be positive.

Guiding Research Questions

- What should we take into account when using the instruments?
- What is the proper procedure to follow to obtain scientific data?
- Is the data obtained in my measurement comparable to that of a student who took temperature in the Dominican Republic, for example?

Scientific concepts

- Calibration
- Accuracy / Precision
- Percentage of error
- Protocol



Materials and Tools

- Several thermometers of different types: mercury, liquid, probe, probe maximum/minimum/current, U-shaped thermometers; in different states of preservation and some with almost ran out batteries.
- Pencil
- Field notebook
- Calculator
- Stopwatch, watch or electronic device
- Ice
- A lab measurement cup
- A calibration thermometer
- Distilled water

What to Do and How to Do It

Beginning -

- As a trigger, the teacher instructs students at the beginning of class to write down the current time on a piece of paper and, reading aloud their notes, compare their records to see if they all wrote down the same value.
- The teacher instructs the students to get together into groups of four.
- The teacher assigns a role to each of the members, which will basically be: i) handling the instrument, ii) timing and iii) making the measurements, and iv) recording in the field notebook.
- Then, the teacher will instruct the students to take one thermometer per group, from an instrument box that the teacher will have reserved only with the thermometers designated for this activity. This box will have been previously prepared by the teacher with a digital thermometer working properly, one with a low battery and one not calibrated, a liquid thermometer with a separated liquid rod, one calibrated and one not calibrated, a U-shaped thermometer, and a mercury thermometer that has been stored unused for a year or more in a cupboard, without having been calibrated and in a horizontal position.

Development -

- The teacher will tell the students to go out to the school playground or the park and separate into groups spreading out in different parts of the place.
- Then the teacher will give them the instructions for the activity: they will have 5 minutes total, they will take a thermometer per group, the field notebook and a pencil. They will measure the ambient temperature. Then they will return to the classroom.
- Once in the classroom, one group at a time will write down the temperature data obtained in one column on the classroom blackboard, and in a second column, the type of thermometer used.



- When all the groups are finished, they will have a set of data (probably very disparate) about the temperature that they all recorded at the same time and study site.
- The teacher will ask why all (or most) of the measurements are different and why they think this might be. The teacher will give them a few minutes to think about their answers and then guide them with the next questions:
 - How do they know the thermometer was in the right condition to measure?
 - Did everyone use exactly the same procedure to measure?
 - Is one repetition enough to know that the measurement is correct?
 - Do the different thermometers measure the same way?
- The teacher will give them 5 more minutes to check the thermometers and look for possible sources of error based on the questions posed by the teacher. After the students come up with possible explanations for the sources of error, the teacher will explain the different sources of error in detail and give examples of each situation for a better student understanding:
- It is necessary to calibrate instruments before use (this applies to thermometers, infrared thermometers, pH meters, conductivity meters, soil thermometers, etc.) and the teacher will teach the students the method for calibrating air temperature thermometers. He/she will emphasize that thermometers should be calibrated periodically, after repair, when they have been stored for a long time without use, and especially before use.
- In the case of probe thermometers, it is important to store them without batteries so that they do not continue consuming energy, and if when the students turn on the instrument, they notice that the screen flickers, does not work well or does not even turn on, they should remember to change the battery in case it ran out.
- On the other hand, the teacher will also show the students how to store the thermometers, which should be kept vertically and in a place that is neither too humid nor too warm. The teacher can also point out to them, with a thermometer with a separated liquid rod, that the instruments can be damaged by ill use or storage, showing them the methods for rejoining a rod (shaking it vigorously with the hand up and down, or placing it over a heat source so that the liquid expands and rejoins the rod).
- The teacher will inform them that in order to ensure that all measurements are carried out under the same conditions and quality data is obtained, GLOBE uses a method called "Protocol", which is the standardized scientific process to take a measurement, and that the data obtained are comparable to those taken by any person in another part of the world, who has used the same instrument and protocol.
 - As part of the protocol, they will also be told why to take the measurement three times: one is not enough, if there are two, you may get two different values, but if there are three, surely the three are similar or at least two of them, which allows students to achieve a more accurate data by averaging the three measurements.
- Problems caused by the observer. The individual is a highly error-prone observer. Despite his/her best intentions, the human observer is limited by the sensitivity of his perceptual system, by the marks and categories available to him/her for the organization of his/her sensitive experience, as well as by motivational and psychological aspects.... From this, his/her inability to repeat an observation in exactly the same way and obtaining the same result is deduced (variability). Possible solution, to repeat the observation and take the average of the observed



values, use discriminating and measurable categories, etc. (<http://www4.ujaen.es/~eramirez/Downloads/theme4>).

- This can be reflected, for example, when looking at the thermometer to measure temperature, the observer's eye must be in a straight line with the thermometer, because if it is looked at from below or from above, the measurement will be incorrect (see Fig. 2). The same is true for the rain gauge, where it is the lower part of the meniscus in the measuring tube that should be measured, not the edges.

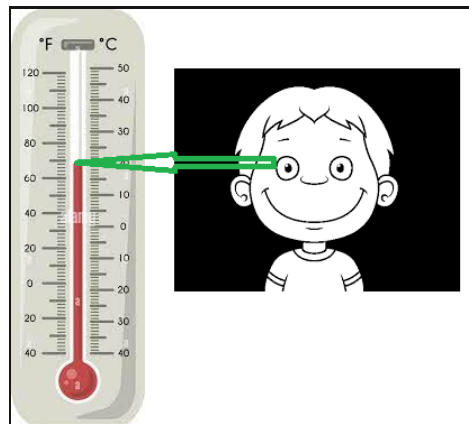


Fig. 2: Correct position of the observer's eye

- Another factor that will influence the measurement is the site chosen for the measurement. Therefore, if different groups measured in different places in the courtyard, some in the sun, others in the shade of trees, others in the shade of their body, they will probably have obtained different measurements. The protocol indicates that the ambient temperature is taken in the shade of the body of the person taking the measurement.
- The type of land cover on which the students are standing also affects the temperature value, for example, asphalt or cement store more heat on the surface than grass, which absorbs part of the sun's rays and reflects the rest). It is recommended to do it on natural cover, within the existing possibilities.
- The environmental conditions in which the measurements are taken are another element that affects the accuracy of the data. For example, in the case of outdoor temperature measurements, the fact of starting the measurement with sunshine and that during the three measurements required by GLOBE the sky is partially cloudy, will cause the temperature to drop slightly during the measurements; which will be changing the environmental conditions in the middle of the data collection. To avoid this type of effect on the measurements, it is best to make sure beforehand that all 3 measurements are taken under the same conditions: always sunny or always cloudy.
- Another stage where data management is important is data entry and analysis (organization in charts, graphs, etc.). Consistency and standardization of data handling is essential to avoid errors in data entry into a database. Consider establishing the format of the data beforehand to avoid generating inconsistencies among the different people who enter it. Example: the different formats for entering the date corresponding to the data collection: dd/mm/yy, mm/dd/yy, mm/dd/yyyy, etc.; the units of measurement in which the measurements are taken: temperatures in °C, °F, °K; length in mm, cm, m, etc.



Ending -

- To end the activity, the teacher asks the students to go back out to the courtyard, once they have calibrated all the thermometers and learned the protocol, and following the steps in the Field Guide, take the temperature measurement again under the protocol requirements.
- Then, when the students return to the classroom, they again write down the data obtained on the blackboard and surely, the data values obtained will be much more accurate than the first time.
- Ask the students to discuss whether there might have been any errors and what might have caused them.

Frequently Asked Questions

What kind of thermometers can I use for this learning activity?

As this is a practice to understand the importance of calibration and to respect the protocol to obtain research quality data, any thermometer will do: broken, with a separated rod, uncalibrated, mercury thermometers (although GLOBE does not recommend them and they are no longer used in many countries, they are useful for this particular activity), alcohol, calibration, wall, probe, U-shaped thermometers.

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