What is the Right Answer?

Purpose

To introduce students to the concept that sometimes there is no one "right" answer to a question or measurement

Overview

Students learn to be careful when searching for a "right" answer to questions such as "What time is it?" by comparing multiple measurements of the time-of-day. Students gain an intuitive understanding of the characteristics of imperfect measurements. Using different clocks, students simultaneously record the displayed times. The resulting time measurements are converted from minutes and seconds to seconds. These measurements are plotted to illustrate the mathematical techniques of averages and deviations from an average.

Student Outcomes

Learn how to measure time.

Understand the accuracy of a measurement.

Science Concepts

Levels of measurement incorporate degrees of accuracy.

There are mathematical techniques for characterizing the accuracy of a measurement.

Science Inquiry Abilities

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and explanations using evidence.

Time

Approximately one class period

Level

Elementary - do only the clock comparison step

Middle and Secondary - do the full activity

Materials and Tools

At least one clock per student, any type, which shows seconds, will suffice

Paper and a writing tool for each student to record times

Copies of the *GPS Investigation Time Measurements Work Sheet* and plot forms for each student

Optional but desirable:

Calculator with addition, subtraction, multiplication and division functions

GPS receiver (Used as a source of standard time. Access to a GPS receiver is not essential. If available, use it as a highly accurate clock.)

Preparation

Provide at least 10 clocks for use by the class. The students can use school clocks or bring in clocks from home.

Prerequisites

Beginning levels - ability to read time on a clock

Intermediate and advanced levels - plotting and graphing skills

Background

GPS measurements will be made by a large variety of instruments scattered over large geographic regions and long periods of time. Efforts have been made to recommend instruments of sufficient accuracy and resolution to suit the underlying scientific goals. However, there will be variations between the measurement values because of the diversity of instrument conditions and student researchers.

What Is the Right Answer?

When people make measurements, they usually wish to know something about the quality of their acquired values. Typically someone asks, “How far am I from the right answer?” or “Did I get the right answer?” This assumes that there is a right answer against which to compare the measured value.

Sometimes there is a right answer. However, when scientists begin measuring a quantity, especially if it is the for first time, there may not be a standard against which to compare one’s results. If you have the only instrument for making a particular measurement and you have no reason to doubt the values that you are recording, then it is reasonable to consider yourself to be the standard.

A problem comes when there exist either multiple measurement instruments or someone claims to be able to produce “the right” or better results. It has been said, “Someone with two watches does not know the time.” In this case, you, the scientist, have to decide how to handle potentially different measurement values or how to choose which measurements and standards to use.

Resolution and Accuracy Using Clocks

The number of digits or the smallest unit of time that can be read reliably by a person observing a clock is called the instrument’s resolution. Thus a digital clock that displays 12:30:21 (meaning 12 hours, 30 minutes, and 21 seconds) has a resolution of about one second because the clock user can read the clock to the nearest second. An analog clock (which has hour, minute, and second hands) also has a resolution of about one second because you can read the second hand to about one second. An analog clock with only hour and minute hands has a resolution of only about one minute unless you consistently can determine the location of the minute hand between individual minute markers.

However, the clock that can be read to a resolution of 1 second can deviate from some standard time source from a fraction of a second up through a few hours. The ability of a clock to maintain “correct” time is called its accuracy. Therefore, if you have a clock that gains 10 minutes every day, you still may be able to read it to a resolution of a single second, but it is accurate to only 10 minutes per day. Some say that this clock has an error of 10 minutes per day.

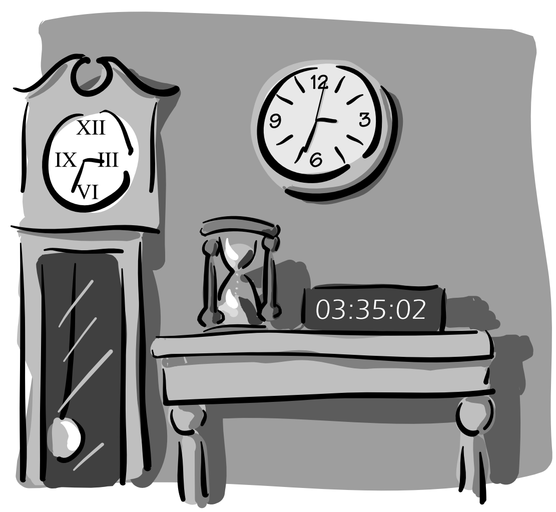


Figure GPS-RA-1: A collection of clocks, all with different accuracies and resolutions.

Clocks are machines that display a count of something that changes as time passes. Early clocks determined time by counting falling drops of water or grains of sand. These were not particularly accurate because size of water droplets or an amount of sand falling is hard to control. Later clocks counted the swings of pendulums, the vibrations of tuning forks, mechanical oscillations in electrically stimulated crystals, and atomic resonances. Each of these subsequent clocks is more accurate than its predecessor, and all depend on the increased stability and repeatability of an underlying cyclical physical process. See Figure GPS-RA-1.

For all clocks to display the same time, ideally each clock would have to be set to the same time simultaneously and experience the same environmental and mechanical conditions. This rarely happens. Clocks typically are set at different times from different references, having different accuracies, with different constructions, and experience different environments. A given collection of clocks will tend to offer a collection of slightly varying time values. This variation in measurement values will be true of most instruments for the temperature, distance, and other measurements of the GLOBE Program (thermometers, tape measures, etc.).

In the case of deciding when to feed a pet, an error of a few minutes from day to day may be insignificant. However, a Global Positioning System location measurement depends on the clocks onboard the satellites being highly accurate. An error of a single microsecond (1/1,000,000 second) may cause the displayed GPS location to be in error by more than 300 meters. The desired resolution and accuracy depend on you (the user) and your understanding of your application.

Time Standards

Until the advent of the American railroads in the late 1800s, there were few widely accepted standards for time. Each population center had its own clocks that were usually referred to local solar noon when the sun peaks in the sky or some other celestial event. However, once one moves through 15 degrees of longitude or about 1600 kilometers along the equator, the time of local noon has changed by an hour. To facilitate consistent scheduling across continent-sized areas of our planet, time zones were created and implemented. The railroads needed and presented a common time reference frame.

Today all time zones are referenced to a longitude of 0 degrees that goes through Greenwich, England. Greenwich houses one of the great astronomical observatories. It was established for standardization of time for British naval navigation. Thus, the time in Greenwich, England, is used as a standard and is called Greenwich Mean Time (GMT), Universal Time (UT), or sometimes Zulu time. (Zulu refers to zero or the 0 degree longitude.) In the GLOBE *GPS Protocol* you will use the Universal Time (UT) designation for your measurements.

The Navy and the National Institute of Standards and Technology (NIST) within the United States and telephone companies maintain standard times using highly accurate atomic clocks that count the vibrations of a variety of atoms under well-defined conditions. The U.S. radio station with the call letters WWV continuously broadcasts the time of day in English on the short-wave radio frequencies of 5, 10, 15, 20, and 25 MHz from Boulder, Colorado. These frequencies themselves are locked to atomic time standards. The Canadian government provides a similar service in both English and French with their short-wave radio station CHU on 7.335 and 14.670 MHz. Many such services exist globally.

The Global Positioning System

The Global Positioning System has a series of satellites that broadcast timing signals from highly-accurate onboard atomic clocks. Therefore, a GPS receiver can determine its time to an accuracy comparable to that of the clocks on the satellite. The GPS receiver can even remove the delay due to travel time between the satellite and the terrestrial receiver because the receiver knows both the satellites' and its own locations. Thus, GPS receivers have become the best alternative to having your own atomic clock.

Telecommunications

Computer communication depends on time measurements that must be substantially more accurate than the rate at which the data flows. If one is using a 14.4k bit/second modem to transfer data via the Internet, a new information bit may be presented to the modem every 1/14,400 seconds or 70 microseconds. Thus, the clocks in the computer hardware must have sufficient resolution to separate each individual 70 microsecond slice of time and must be sufficiently accurate between the transmitting and receiving computers' clocks so as not to become unsynchronized by more than a fraction of the 70 microseconds. These needs are met easily by the use of quartz crystals that can be made to vibrate mechanically at chosen values of between 10 thousand and 100 million times per second. The vibrations are electronically counted by a digital circuit to determine the amount of time which has passed.

What To Do and How To Do It

Step 1. Get the Clocks

Locate at least ten (and preferably more) operating clocks that display time to a resolution of one second. Assign a student to each clock, and declare one student to be the master timekeeper. In a classroom situation where many students may have wrist watches with one second resolutions, these clocks will suffice. Wall clocks displaying seconds in a variety of different rooms are also adequate. Each student should be prepared to record a time and be able to see or hear the master timekeeper.

Step 2. Take the Measurements

Centrally locate the master timekeeper. At 30 minutes and zero seconds after the hour, this student is going to indicate to the other students to record their clocks' displayed time values to the nearest second. Perhaps ten seconds before the designated time, the master time keeper may begin counting down aloud to prepare the other students.

Although any particular time will work, choosing 30 minutes into the hour increases the chances that during the measurements no clocks will advance to the next hour and thus complicate later arithmetic processing.

Advanced students: Have the students perform the computations and graphing.

Other students: The teacher performs the computations and graphing outside of class for later presentation and discussion. While younger students may not understand the arithmetic, they do understand how the shape of the histogram plot appears for various clock accuracies.

Step 3. What time was it?

For details, see the sample *GPS Investigation Time Measurements Work Sheet* and instructions.

Determine the average of all time-of-day measurements.

To determine the average time of day when the data were recorded:

Determine the number of seconds past the hour for each participant's recorded time.

Add these seconds values to produce a sum.

Divide by the number of participants to produce the average time.

Convert this back to minutes and seconds and record.

Step 4. Are our clocks any good?
Determine Deviation from the Average.

For each participant, compute the difference of each participant's time value from the average. Do not keep the sign. All results are positive. Add these together to produce a sum. Divide this sum by the number of participants to produce the average deviation. The average deviation is a measure of how far each measurement is from the average time

Plot differences from the average of our recorded times. See *Occurrences Versus Differences Work Sheet*.

Each bin is 10 seconds wide and is 10 seconds from the average number of seconds. Record the average number of seconds in the center box. Place an X in the appropriate bin for each participant's number of seconds into the hour. This type of plot is called a histogram.

How would the plot be different if we had a more or less accurate collection of clocks?

Further Investigation

If you have access to a GPS receiver, use its time to set a clock that can be used as the master clock for the measurements. The GPS receiver's displayed time will probably be the most accurate time available.

If we have higher quality clocks, how will our computed average deviation change?

Students with access to spreadsheet computer programs may wish to automate the arithmetic computations found on the work sheet.

Advanced students may wish to investigate the statistical concepts of standard deviation and variance.

Student Assessment

Quantitative

Ask students how the histogram plot would be different if they had a better or worse collection of clocks. Better: X's grouped closer together. Worse: further apart. Could they record clock values? Could they understand the arithmetic? Should any of the data be rejected? If a data sample is obviously inappropriate, such as from a stopped clock, yes!

Qualitative

The student should be able to describe situations in which it is and is not reasonable to demand a "right" answer. The student should be able to list examples of measurements that they make in their lives and should contrast between the available and desirable resolutions and accuracies for these measurements. The student should take responsibility for determining the accuracy and resolution necessary for the measurements required by an investigation.

Figure GPS-RA-2: An Example Time Measurements Work Sheet

GPS Investigation

Time Measurements Work Sheet

Your Name: *Jordan Malik* Today's Date: *April 14, 2001*

Participant Number	Recorded Times (Hr	Min	Sec)	Seconds past the Hour (Seconds)	Average (seconds)	Difference from Average (Seconds)	Average of Differences (Seconds)
1	12	30	0	1800		6.9	
2	12	29	54	1794		12.9	
3	12	30	1	1801		5.9	
4	12	30	15	1815		8.1	
5	12	31	1	1861		54.1	
6	12	30	25	1825		18.1	
7	12	30	3	1803		3.9	
8	12	30	7	1807		0.1	
9	12	29	22	1762		44.9	
10	12	30	1	1801		5.9	
11					1806.9		16.08
12	Ten students Participated				Average Number of Seconds into the Hour		Average Deviation
13							
14							
15							
16							
17							Difference Sum divided by number of Participants
18					Sum divided by number of Participants		
19							
20							
10	= Number of Participants			18069	= Sum	160.8	= Difference Sum

Average Time

(Minutes)	(Seconds)
30	6.9

Instructions

Record Times

Computations

Determine the number of seconds past the hour for each participant's recorded time.
(Total Seconds = Minutes x 60 + Seconds)

Determine the average time.
(Average time = Sum of seconds / Number of participants)

Compute the difference of each participant's time value from the average.
(Difference = Seconds into the Hour - Average Seconds)
(Do not keep the sign – All results are positive numbers)

Determine the averages of the differences.

Plot Histogram

Record the average number of seconds in the center box.
Each bin is 10 seconds away from the average and 10 seconds wide.
Determine the time for each bin by adding or subtracting from the average.
For each number of seconds into the hour, place an "X" in the nearest bin.
(The number of X's should be the same as the number of participants.)

GPS Investigation

Time Measurements Work Sheet

Your Name: *Jordan Malik* Today's Date: *April 14, 2001*

Participant Number	Recorded Times (Hr Min Sec)	Seconds past the Hour (Seconds)	Average (seconds)	Difference from Average (Seconds)	Average of Differences (Seconds)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12			Average Number of Seconds into the Hour		Average Deviation
13					
14					
15					
16					
17					Difference Sum divided by number of Participants
18			Sum divided by number of Participants		
19					
20					
10	= Number of Participants		= Sum		= Difference Sum

Average Time
(Minutes) (Seconds)

Instructions

Record Times

Computations

Determine the number of seconds past the hour for each participant's recorded time.
(Total Seconds = Minutes x 60 + Seconds)
Determine the average time.
(Average time = Sum of seconds / Number of participants)
Compute the difference of each participant's time value from the average.
(Difference = Seconds into the Hour - Average Seconds)
(Do not keep the sign – All results are positive numbers)

Determine the averages of the differences.

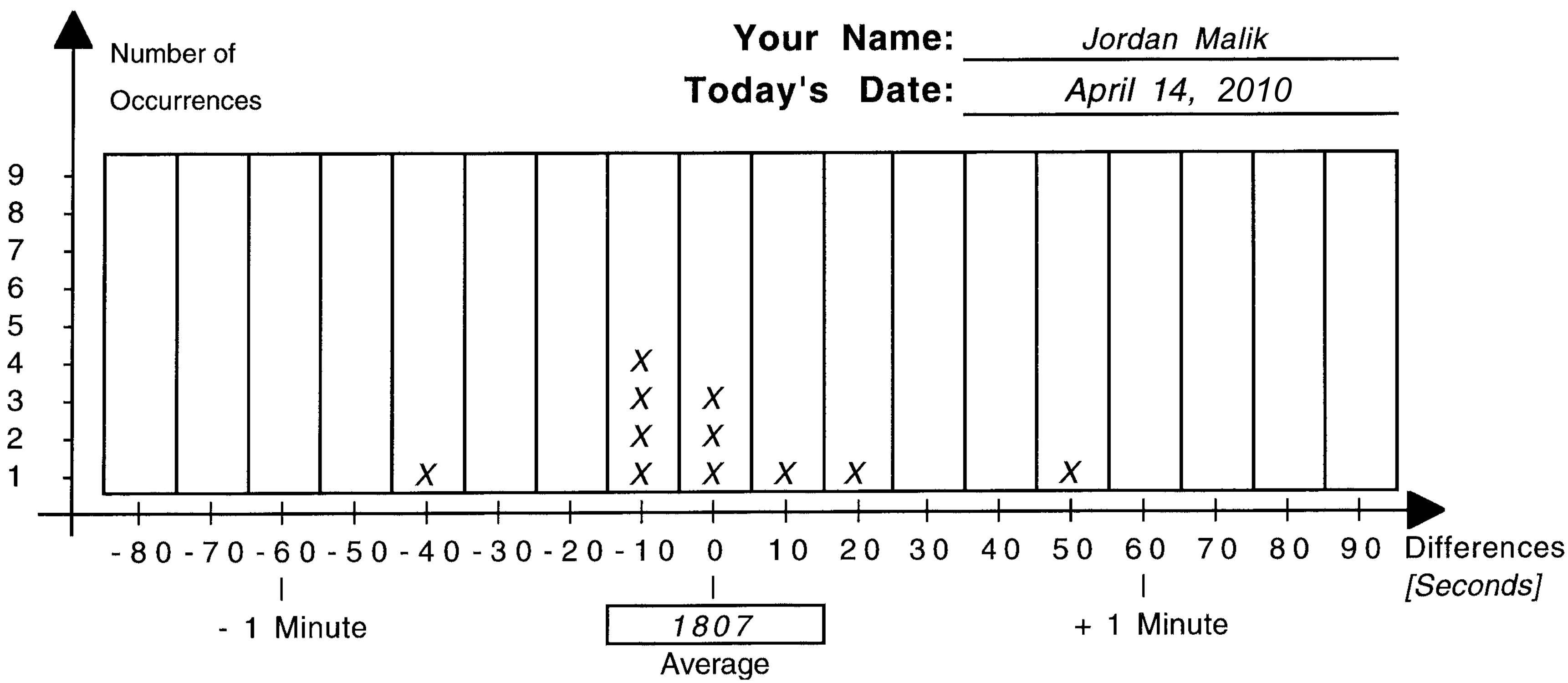
Plot Histogram
Record the average number of seconds in the center box.
Each bin is 10 seconds away from the average and 10 seconds wide.
Determine the time for each bin by adding or subtracting from the average.
For each number of seconds into the hour, place an "X" in the nearest bin.
(The number of X's should be the same as the number of participants.)

Figure GPS-RA-3: An Example Occurrences Versus Differences Work Sheet

GPS Investigation

Occurrences Versus Differences Work Sheet

Plot 1: Histogram of Number of Occurrences versus Differences



GPS Investigation

Occurrences Versus Differences Work Sheet

Plot 1: Histogram of Number of Occurrences versus Differences

Your Name: ____________________

Today's Date: ____________________