wrong	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
right	72	71	70	69	68	67	66	65	64	63	62	61	60	59	58	57	56	55	54	53	52	
score	100	98.6	97.2	95.8	94.4	93.1	91.7	90.3	88.9	87.5	86.1	84.7	83.3	81.9	80.6	79.2	77.8	76.4	75.0	73.6	72.2	

Biologist at Work!

Name _____

Observation: Organisms have parts which can be measured in terms of length. Suppose you previously made some measurements on yourself. With those measurements in mind, you would now have a "human ruler." You could measure a centimeter at a time with one of your fingernails, and could measure longer lengths by "walking" with your thumb and index finger.

Which of your fingernails comes closest to 1 cm in width? left right

thumb index middle ring pinkie

What is the length between your thumb tip and extended index finger tip? ___.___cm

Question: Is my right hand the same size as my left hand?

Hypothesis: My hands are the same size.

Prediction: If my hands are the same size, then the width across my left hand should be the same as the width across my right hand.

Experiment: Width across knuckles of: left hand ___.___cm ... right hand ___.___cm

Was this really an experiment? yes no

If no, why not? _____

_____

If this is not an experiment, what is it? _____

Analysis:

My left hand is: wider than the same as narrower than my right hand.

Decision:

The hypothesis: "My hands are the same size" is: rejected not rejected

There is very little doubt about the outcome here because you have asked a discrete question with a measurable answer.

Did the prediction thoroughly test the hypothesis? yes no

If not, what else might we measure to more thoroughly test the hypothesis?
(hint: the key word is "size"!)

1. _____ 2. _____

Most investigations yield not only answers but more questions as well. Scientists are curious people! We might also wonder whether the results of our study can be generalized to the entire human population, for example.

Koning, Ross. E. 1994. Biologist at Work. *Plant Physiology Information Website*.
http://plantphys.info/plants_human/labpdf/biologistatwork.pdf

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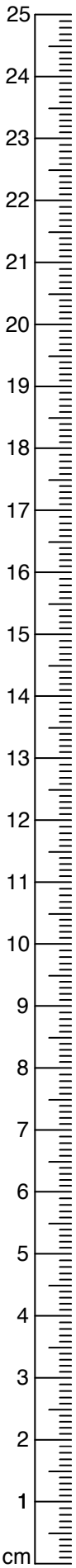

Observation: You now know something about your own two hands. You also notice that not everyone in the room is the same size overall.

Question: In spite of different absolute body sizes, does everyone have hands of equal width?

Hypothesis: The human population has hands of equal width. [a null hypothesis]

Prediction: If the human population has hands of equal width, then a sample of the human population should have hands of equal width.

Notice that we cannot go out and measure the hands of the entire human population, so we must settle for a sample. We hope we can take a representative sample (that is a random sample). Our sample will be all the people in this laboratory.

Would this be a random sample of the population? yes no

If it is not a random sample, why isn't it?

1. _____

2. _____

We also hope that our sample is sufficiently large. In spite of any shortcomings in our sample, we will continue our analysis since we lack a better sample.

Experiment: Your instructor will help you post your hand width data along with your classmates' data on the board. Additional data will be recorded on a computer.

By collecting lots of data, do we now have an experiment? yes no

If no, why not? _____

_____

If this is not an experiment, what is it? _____

Analysis: Clearly we have various widths in each sample and must now include an assessment of this variation in preparing for our decision. Calculate the mean (average) width and the standard deviation of the samples. The latter gives us some measure of the variation (or spread) around the mean. Most calculators will determine the mean and standard deviation for you, using the formulae shown below, but we will let a computer do this work for us!

$$\text{mean} = \overline{x} = (\Sigma_{i=1}^{n} x_i) / n$$

$$\text{standard deviation} = \{ [\Sigma_{i=1}^{n} (x_i - \overline{x})^2] / (n-1) \}^{1/2}$$

We will use Microsoft Excel™ to help us with these calculations.

After powering up the computer, select Excel from the dock at the bottom of the screen. This should open a dialog box, which you can dismiss by clicking on the blue "Open" button. A blank spreadsheet will appear on the monitor screen. In the cell A1 type "Left" and in the cell B1 type "Right." Enter the data from the board in the columns beneath the words (left hand data in A2 to A25, and right hand data in B2 to B25).

To calculate the means: In A26 type "=average(A2:A25)" and hit return. Copy A26 and paste it into B26. To calculate the standard deviations: In A27 type "=stdev(A2:A25)" and hit return. Copy A27 and paste it into B27. To fix the rounding problems, select A26:B27 and then select Format-Cells-Number- (Format Tab on Ribbon) and set the decimal places to one more than we have precision in our measurements (in this case millimeters, so we want two decimal places—the default). Record your values below:

	Left hands in sample:	Right hands in sample:
Mean width (cm)	.	.
Standard Deviation (cm)	.	.
Student's t-test value of p	.	same different

In general, if the spread about a mean (Standard Deviation) is greater than the difference between the two means, we worry whether what we are observing is meaningful or not. But how will we know with reasonable certainty? We need to do a statistical test of our hypothesis.

Student's T-Test:

Excel can quickly carry out a t-test, which compares the means of two samples and gives us a probability (p) value that the result we observed could be observed again with the null hypothesis. In A28 type: "=ttest(A2:A25,B2:B25,2,1)" hit return, and set the cell to show 3 decimal places. In general we choose to reject a null hypothesis when this value is less than the arbitrary value (α) of 5% (0.05…so now you see why we chose three decimal places).

In B28 type: "=if(A28>0.05,"Same","Different")" and hit return. You can see that Excel can even automate your decision making. The beauty of a spreadsheet is that once you have produced it, you can change any of the raw data numbers and the rest of the calculations are repaired automatically!

Some details: the ttest function in Excel compares the two data ranges you told it were of interest (A2:A25 and B2:B25). We told it to perform a two-tailed (2) test and that our data were paired (1), meaning we had left and right hand data from the same person in each row of our data chart. The returned value of p was compared to an α value, which is suitable for everyday biology projects. In some kinds of projects you might want to allow more error (more than 5%), but in others you might want to allow less error. Allowing 5% gives a reasonable balance between Type I and Type II statistical errors for "typical" tests of null hypotheses.

Decision: Based upon Student's T-test, the hypothesis:

"The human population has hands of equal width" is is not rejected.

There are two reasons for this:

1. _____

2. _____

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Observations: A single bag of beans was purchased from the store. Some of the beans were soaked in water overnight, the rest from the same bag remain dry. Clearly the soaking has had some effect upon length.

Question: Does soaking beans cause them to expand?

Hypothesis: Soaking does not cause beans to expand. [null hypothesis]

Prediction: If soaking causes beans to expand, then beans will be significantly larger when they are soaked than beans which have been kept dry.

Experiment: A sample of beans was divided into two sub-samples. One sub-sample was placed in water, the other sub-sample was kept in dry conditions. Use a metric rule and a balance to their greatest precision to determine the length and weight of each of 10 beans from each sub-sample.

Was this a true experiment? yes no

Soaked Beans		Dry Beans	
length	weight	length	weight
mm	. g	mm	. g
mm	. g	mm	. g
mm	. g	mm	. g
mm	. g	mm	. g
mm	. g	mm	. g
mm	. g	mm	. g
mm	. g	mm	. g
mm	. g	mm	. g
mm	. g	mm	. g
mm	. g	mm	. g

	Soaked Beans	Dry Beans
Mean Length (mm)	.	.
Standard Dev.	.	.
t-test p =	.	same different

	Soaked Beans	Dry Beans
Mean Weight g)	.	.
Standard Dev.	.	.
t-test p =	.	same different

Analysis: Carry out Student's t-tests to see whether there are any significant differences between the mean lengths and weights of the two sub-samples. In this case the formula for t-test needs to end with 1,3. We get to do a one-tailed test as our subjects clearly must have gained water during the treatment, but we do not have paired data this time. Therefore the 3 tells Excel that our two data sets come from different distributions. Based on the t-test, are the two mean weights significantly different?

Decision:

Based on Student's T-test, the hypothesis:

"Soaking does not cause beans to expand" is: rejected not rejected

Our hypothesis used the term "expand" and our prediction used the term "larger." In our experiment we measured the weight of the beans.

What weight adjective would describe the soaked beans? _____

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Observation: Our soaked beans sure do seem larger than the dry beans, but how can we measure the volume of an oddly shaped living-bean?

Question: Does soaking beans cause them to expand?

Hypothesis: Soaking does not cause beans to expand. [null hypothesis]

Prediction: If soaking does not cause beans to expand, then beans will not be significantly larger when they are soaked than beans left dry.

Experiment: Measure the volume of bean seeds by displacement of water in a graduated cylinder. Put exactly 14 mL of water in the graduated cylinder. Now slowly add beans until the water level comes just <u>below</u> the 25 mL mark; do not put in more than 10 beans. Calculate the volume per bean by dividing the total volume of beans added by the number of beans added.

	Soaked Beans	Dry Beans
Final Liquid Level	. mL	. mL
Starting Level	-<u>14</u> mL	-<u>14</u> mL
Total Volume of Beans Added	. mL	. mL
Number of Beans Added	beans	beans
Volume per Bean	. mL	. mL

Is this really an experiment? yes no

The group of dry beans receiving no treatment is the _____ group.

The group of soaked beans is called the _____ group.

Analysis: Examining the volume per bean, there is a striking difference.

Can we perform a t-test on these data? yes no

The degrees of freedom calculation ($=N_1+N_2-2$) specifies how free you are to do a t-test.

How free are we do to this test? The degrees of freedom are: _____

How could we redo our measurements so that we <u>could</u> use a t-test for our analysis?

1. _____

2. _____

We will not make any further measurements, but perhaps we may satisfy our need for significance by recalling that scientists find 5% error acceptable.

Calculate the ratio of volume per soaked bean to volume per dry bean ____. ____ ____

The soaked beans occupy _____% of the volume of the dry beans.

Is there at least a 5% difference between the beans? yes no

Decision:

Based on a displacement test, the hypothesis:

"Soaking does not cause beans to expand" is: rejected not rejected

By having hypotheses rejected, are we poor scientists? yes no

<u>Why</u> did we not have the option to "prove" any of our hypotheses?

Because of_____

Homework: redo all Excel work at home, check rounding and leading 0 for all data!!

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