wrong	0	1	2	3	4	5	6	7	8	9	10	11	12	13	
right	64	63	62	61	60	59	58	57	56	55	54	53	52	51	
score	100	98.4	96.9	95.3	93.8	92.2	90.6	89.1	87.5	85.9	84.4	82.8	81.3	79.7	.

Scientist 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? [Right / Left] [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:

The width of my left hand is: [wider than / the same as / narrower than] that of 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. Scientist at Work. *Plant Physiology Information Website*. http://plantphys.info/plants_human/labpdf/scientistatwork.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.

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? _____

_____

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' on the board.

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!

$$\text{mean} = \bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad \text{standard deviation} = \sqrt{\frac{\left(\sum (x_i^2)\right) - (\bar{x})^2 n}{n-1}}$$

	Left hands in sample:	Right hands in sample:
Mean width (cm)		
Standard Deviation (cm)		

Student's T-test

We will let a computer determine the t-statistic for our samples. The formula it uses assumes $n_1=n_2$:

$$t_{stat} = \frac{(\bar{x}_1-\bar{x}_2)\sqrt{n}}{\sqrt{s_1^2+s_2^2}} = \boxed{\quad}$$

Ignore any negative sign carried by the t-statistic.

This t-statistic is compared with a t-value found in a t-table.

The table value is found by using a **row** defined by the degrees of freedom:

$$n_1+n_2-2 = \boxed{\quad}$$

and a **column** defined by the acceptable level of error. As scientists, what level of error is acceptable? Most scientists admit that 5% of the time chance alone will explain errors. Our table includes a 5% column.

Circle the pertinent table value in the table ➳ ➳ ➳ ➳

Decision Rules:
- If the t-statistic is greater than the table value, the two samples are **significantly different**.
- If the t-statistic is less than or equal to the table value, then the samples are **statistically the same**.

T-table

Degrees of Freedom	Critical Levels 0.10	0.05	0.01
1	6.314	12.706	63.657
2	2.920	4.303	9.925
3	2.353	3.182	5.841
4	2.132	2.776	4.604
5	2.015	2.571	4.032
6	1.943	2.447	3.707
7	1.895	2.365	3.499
8	1.860	2.306	3.355
9	1.833	2.262	3.250
10	1.812	2.228	3.169
11	1.796	2.201	3.106
12	1.782	2.179	3.055
13	1.771	2.160	3.012
14	1.761	2.145	2.977
15	1.753	2.131	2.947
16	1.746	2.120	2.921
17	1.740	2.110	2.898
18	1.734	2.101	2.878
19	1.729	2.093	2.861
20	1.725	2.086	2.845
21	1.721	2.080	2.831
22	1.717	2.074	2.819
23	1.714	2.069	2.807
24	1.711	2.064	2.797
25	1.708	2.060	2.787
26	1.706	2.056	2.779
27	1.703	2.052	2.771
28	1.701	2.048	2.763
29	1.699	2.045	2.756
30	1.697	2.042	2.750
40	1.684	2.021	2.704
60	1.671	2.000	2.660
120	1.658	1.980	2.617
∞	1.645	1.960	2.576

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

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

There are two reasons for this decision:

The statistical test tells us: _____

The sample providing the data was: _____

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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 causes beans to expand.

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 balance to its greatest precision to determine the weight of each of 10 beans from each sub-sample.

Soaked Beans	Dry Beans

Was this really an experiment? Yes No

If no, why not? _____

_____

If not an experiment, what is it?_____

	Soaked Beans	Dry Beans
Mean Weight (g)		
Standard Dev.		

Analysis: Carry out a t-test to see whether there is any significant difference between the two sub-samples.

T-statistic: _____ Degrees of Freedom: _____ Table Value: _____

Based on the t-test, are the two means significantly different? yes no

Decision:

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

"Soaking causes beans to expand" is: rejected / not rejected

Our hypothesis used the term "expand" and our prediction used the term "larger." In our experiment we tested the weight of the soaked 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. [note alternate!]

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 below 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	-14 mL	-14 mL
Total Volume of Beans Added	mL	mL
Number of Beans Added	beans	beans
Volume per Bean	mL/bean	mL/bean

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

If No, why not? _____

If we wanted to redo our volume measurements, how could we do them so that we could use a statistical test for our analysis?

_____

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 the volume per soaked bean to the 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

Why did we choose to rewrite our hypothesis this time to its alternate "no effect" form?

_____

_____

By having our hypotheses rejected, are we poor scientists? Yes No

Why did we not have the option to "prove" any of our hypotheses? _____

_____

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