Statistics for Sophomores (Yes! 10th Graders can do this!)

2013 Ecological Society of America Life Discovery Workshop

Paul K. Strode

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- When should science students learn statistics?
- What are the standards asking of teachers regarding statistics?
- How I introduce statistics in high school biology by modeling scientific methodology, testing a hypotheses, and generating and analyzing real and really messy data
- Presentation and Discussion: How to build statistics into lab activities we already do

College Science Departments want their students to know statistics

JOURNAL OF CHEMICAL EDUCATION

Article

pubs.acs.org/jchemeduc

A Statistics Curriculum for the Undergraduate Chemistry Major

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Supporting Information

ABSTRACT: Our ability to statistically analyze data has grown significantly with the maturing of computer hardware and software. However, the evolution of our statistics capabilities has taken place without a corresponding evolution in the curriculum for the undergraduate chemistry major. Most faculty understands the need for a statistical educational component, but there is little consensus as to the exact nature of what is to be taught and who should teach it. Because of the large number of courses required for the undergraduate chemistry major, it seems unlikely that requiring a course on statistics will be practical at most institutions. Additionally, it is unlikely that the typical high school education will address the needed statistics or the software training to prepare students for the chemistry courses. Therefore, the chemistry faculty must teach the statistics needed by the majors. The faculty needs to focus on statistics useful to the chemist and this is distinctly different than what is often encountered in biology, medicine, psychology, and business. A starting point is suggested for a discussion on a statistics curriculum that addresses the needs of the chemistry majors.

NO

Schlotter, N. E. 2013. A statistics curriculum for the undergraduate chemistry major. *Journal of Chemical Education* 90:51-55.

The undergraduate chemistry statistics curriculum

Table 2. Summary of Statistics Topics for the Undergraduate Chemistry Program

Topic	Introductory Courses	Advanced Courses
Distributions (Gaussian or random, Student t distribution, and Poisson)	Basic structure, graphical representations, expect the students to understand how to find the Student t value from a table, or using Microsoft (MS) Excel, or equivalent program. Know the difference between two-tail and one-tail problems.	Add the mathematical definitions of the distributions. Include Boltzmann and Maxwell–Boltzmann distributions.
Mean	Expect students to be able to calculate the quantity, understand the difference between the true mean and the sample mean.	Add the calculation of moments of the distributions
Standard Deviation (and Variance)	Expect students to be able to calculate the quantity, understand the difference between the true SD and the sample SD.	Add the calculation of moments of the distributions
Confidence interval	Expect students to be able to calculate the CI for the mean using MS Excel	—
Error propagation	Know that all the measurements to determine a quantity impact the total error, identify most significant error. Possibly use relative errors to get some total error. (Percentage errors)	Be able to apply the full mathematical form for the error propagation to a variety of quantities. Implement in Excel or Mathematica.
Best-fit line	Be able to obtain the best-fit line from Excel.	In addition to obtaining learn the mathematical derivation of the best-fit line. Passing knowledge of how one might derive the nonlinear best fit.
t test	Understand that one is testing whether two means are statistically the same and be able to use Excel to run the test.	—
Error in slope of best-fit line[a]	—	Calculation introduced in Advanced lab. Implement in Excel or Mathematica.
Error in intercept of best-fit line[9]	—	Calculation introduced in Advanced lab. Implement in Excel or Mathematica.
Error in predicting a dependent y value for a given x value based on a data set[9]	—	Calculation introduced in Advanced lab. Implement in Excel or Mathematica.

Schlotter, N. E. 2013. A statistics curriculum for the undergraduate chemistry major. *Journal of Chemical Education* 90:51-55.

College Science Departments want their students to know statistics

■ CONCLUSIONS

The ability to use statistics in the undergraduate curriculum has been greatly expanded by the availability of computers and software that have eliminated the tediousness of doing such an analysis. However, this has put a heavier load on understanding statistical concepts in order to use them appropriately than was required in the past. This evolution in statistics capability has taken place without a corresponding evolution in the curriculum for the undergraduate chemistry major. As chemists, we need to address this curriculum issue.

Requiring an additional course in statistics is difficult in most programs given the course requirements for most undergraduate chemistry degrees. This means that the chemistry faculty will need to cover the educational statistics needs of the undergraduate chemistry major program. A way must be found to cover the statistics needs as efficiently as possible. To cover the statistics needs, a well thought-out curriculum would be a positive step forward. A draft version of such a curriculum is outlined to describe a minimal statistics program to deliver the basic statistics to an undergraduate chemistry major who will work in industry or to continue to graduate programs. The biggest challenge to preparing such a curriculum is keeping it to a minimum, as there are many interesting and useful topics in statistics.

Schlotter, N. E. 2013. A statistics curriculum for the undergraduate chemistry major. *Journal of Chemical Education* 90:51-55.

What the Standards are asking

This PDF is available from The National Academies Press at http://www.nap.edu/catalog.php?record_id=13165

A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas

Chapter 3: Dimension 1: Scientific and Engineering Practices; Practice 4: Analyzing and Interpreting Data
The National Academies Press (2011), p. 3-30

5. Using Mathematics and Computational Thinking

In **science,** mathematics and computation are fundamental tools for representing physical variables and their relationships. They are used for a range of tasks, such as constructing simulations, statistically analyzing data, and recognizing, expressing, and applying quantitative relationships. Mathematical and computational approaches enable predictions of the behavior of physical systems, along with the testing of such predictions. Moreover, statistical techniques are invaluable for assessing the significance of patterns or correlational.

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What the Standards are asking

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A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas

Chapter 3: Dimension 1: Scientific and Engineering Practices; Practice 4: Analyzing and Interpreting Data
The National Academies Press (2011), p. 3-12

Goals

By grade 12, students should be able to:

- Analyze data systematically, either to look for salient patterns or to test whether the data are consistent with an initial hypothesis.
- Recognize when the data are in conflict with expectations and consider what revisions in the initial model are needed.
- Use spreadsheets, databases, tables, charts, graphs, statistics, mathematics, and information technology to collate, summarize, and display data and to explore relationships between variables, especially those representing input and output.

As students progress through various science classes in high school and their investigations become more complex, they need to develop skill in additional techniques for displaying and analyzing data, such as x-y scatterplots or cross-tabulations to express the relationship between two variables. Students should be helped to recognize that they may need to explore more than one way to display their data in order to identify and present significant features. They also need opportunities to use mathematics and statistics to analyze features of data such as covariation. Also at the high school level, students should have the opportunity to use a greater diversity of samples of scientific data and to use computers or other digital tools to support this kind of analysis.

What the Standards are asking

NEXT GENERATION SCIENCE STANDARDS
For States, By States

APPENDIX K – Connections to the Common Core State Standards for Mathematics

2013 nextgenscience.org

Table 2. Middle and high school Science and Engineering Practices that require integrating CCSSM math/statistics tools into NGSS-aligned instructional materials and assessments.

Science and Engineering Practice	6-8 Condensed Practices (subset requiring integration)	9-12 Condensed Practices (subset requiring integration)
Analyzing and Intepreting Data	Apply concepts of statistics and probability from the CCSS (6-8.SP) to scientific and engineering questions and problems, using digital tools when feasible.	Apply concepts of statistics and probability from the High School CCSS (S) to scientific and engineering questions and problems, using digital tools when feasible.

What ARE the Standards asking?

NEXT GENERATION SCIENCE STANDARDS
For States, By States

APPENDIX K – Connections to the Common Core State Standards for Mathematics

MS.ETS1 Engineering, Technology, and Applications of Science
HS.ETS1 Engineering, Technology, and Applications of Science
2013 nextgenscience.org

Analyzing and Interpreting Data
Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

Analyzing and Interpreting Data
Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Use tools, technologies, and/or models (e.g., computational, mathematical) to generate and analyze data in order to make valid and reliable scientific claims or determine an optimal design solution. (HS-PS2-a),(HS-ESS2-i),(HS-ESS3-f)

The College Board gets a little specific

AP® BIOLOGY

Course and Exam Description
Effective Fall 2012

The College Board (2012), p. 98

Science Practice 2: The student can use mathematics appropriately.

The student can routinely use mathematics to solve problems, analyze experimental data, describe natural phenomena, make predictions, and describe processes symbolically. The student also can justify the selection of a particular mathematical routine and apply the routine to describe natural phenomena. The student is able to estimate the answers to quantitative questions using simplifying assumptions and to use

Examples of the use of mathematics in biology include, but are not limited to, the use of Chi-square in analyzing observed versus predicted inherited patterns; determination of mean and median; use of the Hardy-

Weinberg equation to predict changes in gene frequencies in a population; measurements of concentration gradients and osmotic potential; and determination of the rates of chemical reactions, processes and solute concentrations. The student is able to measure and collect experimental data with respect to volume, size, mass, temperature, pH, etc. In addition, the student can estimate energy procurement and utilization in biological systems, including ecosystems.

The IBO does even better, but really?

IBO
Diploma Programme
Biology Guide

Topic 1: Statistical analysis (2 hours)

Impossible!

	Assessment statement	Obj	Teacher's notes
1.1.1	State that error bars are a graphical representation of the variability of data.	1	Error bars can be used to show either the range of the data or the standard deviation.
1.1.2	Calculate the mean and standard deviation of a set of values.	2	Students should specify the standard deviation (*s*), not the population standard deviation. Students will not be expected to know the formulas for calculating these statistics. They will be expected to use the standard deviation function of a graphic display or scientific calculator. **Aim 7:** Students could also be taught how to calculate standard deviation using a spreadsheet computer program.
1.1.3	State that the term standard deviation is used to summarize the spread of values around the mean, and that 68% of the values fall within one standard deviation of the mean.	1	For normally distributed data, about 68% of all values lie within ±1 standard deviation (*s* or σ) of the mean. This rises to about 95% for ±2 standard deviations.
1.1.4	Explain how the standard deviation is useful for comparing the means and the spread of data between two or more samples.	3	A small standard deviation indicates that the data is clustered closely around the mean value. Conversely, a large standard deviation indicates a wider spread around the mean.
1.1.5	Deduce the significance of the difference between two sets of data using calculated values for *t* and the appropriate tables.	3	For the *t*-test to be applied, the data must have a normal distribution and a sample size of at least 10. The *t*-test can be used to compare two sets of data and measure the amount of overlap. Students will not be expected to calculate values of *t*. Only a two-tailed, unpaired *t*-test is expected. **Aim 7:** While students are not expected to calculate a value for the *t*-test, students could be shown how to calculate such values using a spreadsheet program or the graphic display calculator. **TOK:** The scientific community defines an objective standard by which claims about data can be made.
1.1.6	Explain that the existence of a correlation does not establish that there is a causal relationship between two variables.	3	**Aim 7:** While calculations of such values are not expected, students who want to use r and r_2 values in their practical work could be shown how to determine such values using a spreadsheet program.

Error bars to indicate uncertainty

Mean and Standard Deviation

Student’s *t*-Test

Correlation and Regression

Why not give students five basic tools?

1. 95% Confidence Intervals to illustrate uncertainty in summarized data

2. The Student's *t*-Test to compare two means

3. One-Way Analysis of Variance (ANOVA) to compare more than two means

4. The Chi-square Test to compare observed with expected distributions

5. The Pearson Product-moment Correlation Coefficient (r) and Linear Regression (r^2) to determine the strength of a relationship

But we also must build a solid foundation:

- The meaning of the hypothesis in science.
- The difference between a hypothesis and a prediction.
- The null statistical hypothesis (H_0)
- *p*-values
- Degrees of freedom (df)

Statistics for Sophomores (Yes! 10th Graders can do this!)

My Statistics Modules (https://www.fairviewhs.org/staff/paul-strode)

One-Way Analysis of Variance (ANOVA)

Paul K. Strode, Ph.D., Fairview High School, Boulder, CO

ANOVA – a statistical procedure to test hypotheses concerning the means of three or more treatment conditions or levels in an experiment. The ANOVA provides a test of the null statistical hypothesis (H_0) that the population means for three or more groups are equal (and any observed differences occurred by chance) against the alternative hypothesis (H_1) that at least one of the population's means differs significantly from all the others. In other words, that there was a treatment effect as a result of the experiment.

Consider the following hypothetical experiment to test the hypothesis that alcohol may affect the maze running ability of rats. The 247 rats in this lab had a mean maze completion time of 5.4 minutes. The scores in Table 1 show the time in minutes for 40 randomly selected rats in four treatments (conditions) to complete the maze.

Table 1. Effects of alcohol on a maze-running task in rats, *Rattus norvegicus*. Condition 1 is placebo; Conditions 2-4 are 0.1, 1.0, and 2.0 ml respectively. Numbers are time (min) to completion of maze.

Treatment			
Condition 1	Condition 2	Condition 3	Condition 4
4	5	11	16
6	3	13	19
3	4	9	12
9	5	14	9
5	10	8	14
5	4	10	18
8	8	12	15
4	4	15	15
4	5	14	12
5	11	18	13

1. Determine the treatment totals and treatment means, and the grand total and grand mean.
   a. Treatment totals ____________________
   b. Treatment means ____________________
   c. Grand Total of all scores________
   d. Grand Mean ________
2. Determine the degrees of freedom (df)
   a. Between groups (n groups – 1 = 3)_______
   b. Within groups (the sum of (n samples in each condition – 1) = 36) _______

The Chi-square (χ^2) Test

Paul K. Strode, Ph.D., Fairview High School, Boulder, CO

Consider the following scenario:

A teacher had been teaching Biology for 4 years. Over those 4 years, he had kept track of the grade distributions in all of his classes—a total of 570 students. The teacher wondered if his observed grade distribution among his 570 students was rare when compared to what would be expected in a normal population of students. The data are summarized in Table 1.

Table 1. Student grade distributions from 2008-2012 in Biology and the expected distributions for a normal population.

	2008-2012			
Grade	Number of Students	Percent	Expected Percent Distribution in a Normal Population	Expected Distribution of Students in each Category out of 1,482
A	74	13	10	57
B	148	26	20	114
C	194	34	40	228
D	103	18	20	114
F	51	9	10	57
Total	570	100	100	570

Can the teacher conclude that his observed student grade distribution is rare when compared to what would be expected in a normal population? In other words, is his distribution significantly different from a normal distribution, so much that it probably did not occur by chance?

He can do a Chi-square Test on the data to determine the probability that his observed distribution occurred by chance. If the probability that his distribution occurred by chance is equal to or less than 0.05 (1/20), he can conclude that the differences between his observed distribution and what he would expect in a normal distribution are *true differences* and *did not occur by chance alone*. In other words, his students are not normal and may be selecting the class because they are already good at science.

But, before we discuss how we can weave stats into high school biology, I think it is important, at the beginning of the year, to walk your students through an example of messy data collection.

Statistics for Sophomores (Yes! 10th Graders can do this!)

Cold Hands and Loss of Fine Motor Skills

Observation: When my hands are cold, I can't buckle my ski boots.

- Question: Why can't I buckle my ski boots when my hands are cold?

- Experimental Hypothesis: Cold temperatures may suppress fine motor skills.

- Prediction (with method): If I break toothpicks for one minute with my warm hand and then with my cold hand after soaking it in ice water for 5 minutes, then I will break more toothpicks with my hand when it is warm.

Statistics for Sophomores (Yes! 10th Graders can do this!)

Cold Hands and Loss of Fine Motor Skills

Observation: When my hands are cold, I can’t buckle my ski boots.

- Hypothesis in science: a *tentative* and *testable* **EXPLANATION** for an observed phenomenon in nature.

- Prediction: a specific and measurable forecast or prophecy about some future event—e.g. the outcome of an experiment.

- The following statement IS NOT a hypothesis:

If I add salt to water then the water will boil at a higher temperature compared to distilled water.

Statistics for Sophomores (Yes! 10th Graders can do this!)

Cold Hands and Loss of Fine Motor Skills

Observation: When my hands are cold, I can’t buckle my ski boot.

- Experimental Hypothesis: Cold temperatures may suppress fine motor skills.

- Null Statistical Hypothesis (H_0): There is no difference between the mean number of toothpicks broken by the cold hand and the mean number of toothpicks broken by the warm hand and any observed differences likely occurred by chance.

- i.e. the means are statistically indistinguishable.

Statistics for Sophomores (Yes! 10th Graders can do this!)

Dominant/Nondominant Hands

Observation: I use one hand more often than the other hand.

- Question: Why do I use one hand more often than the other hand?

- Experimental Hypothesis: The dominant hand may perform fine motor skills better than the nondominant hand.

- Prediction (with method): If I break toothpicks for one minute with my nondominant hand and then with my dominant hand, then I will break more toothpicks with my dominant hand.

Statistics for Sophomores (Yes! 10th Graders can do this!)

Dominant/Nondominant Hands

Observation: I use one hand more often than the other hand.

- Experimental Hypothesis: The dominant hand may perform fine motor skills better than the nondominant hand.

- Null Statistical Hypothesis (H_0): There is no difference between the mean number of toothpicks broken by the dominant hand and the mean number of toothpicks broken by the nondominant hand and any observed differences likely occurred by chance.

- i.e. the means are statistically indistinguishable.

Your investigation…

With your non-dominant hand, you will break as many toothpicks as you can in 60 seconds.

Repeat with your dominant hand.

Rules:

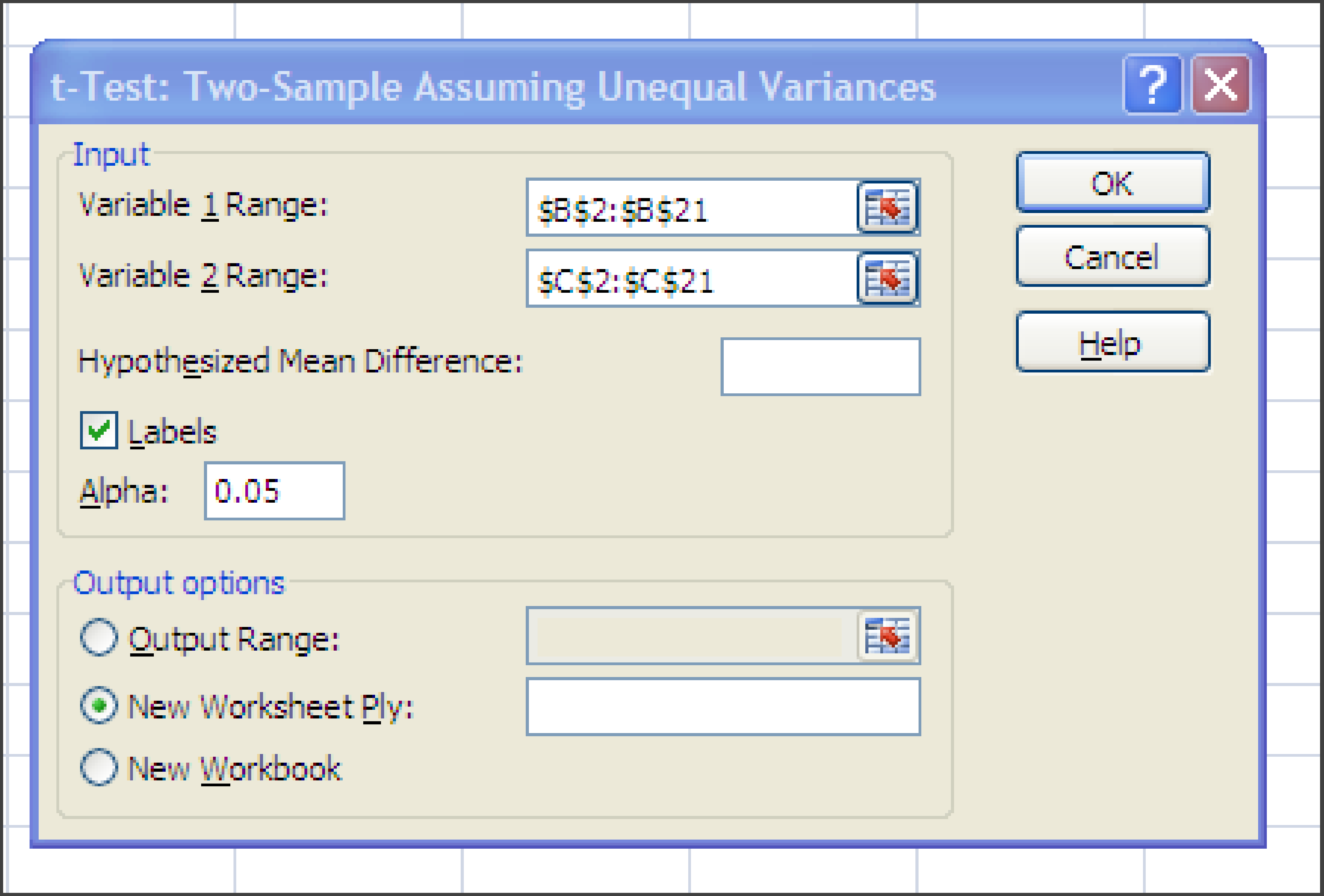
-toothpicks must be taken from the container, one at a time

-you must pick up the toothpick by the tip

-you may only use one hand during the 60 second testing period

-break one toothpick at a time

Calculate t-test on EXCEL



Calculate t-test on a graphing calculator:

- Press **STAT**
- Select **1:Edit**
- Enter the data as two lists
- Press **STAT**
- Highlight **TESTS**
- Select **4:2 Sample T Test**
- Scroll down and select **CALCULATE**

Calculate stats online:

- *t*-Test: http://studentsttest.com/
- ANOVA: http://turner.faculty.swau.edu/mathematics/math241/materials/anova/
- Chi-square: http://graphpad.com/quickcalcs/chisquared1.cfm
- Correlation Coefficient: http://www.alcula.com/calculators/statistics/correlation-coefficient/

Statistics for Sophomores (Yes! 10th Graders can do this!)

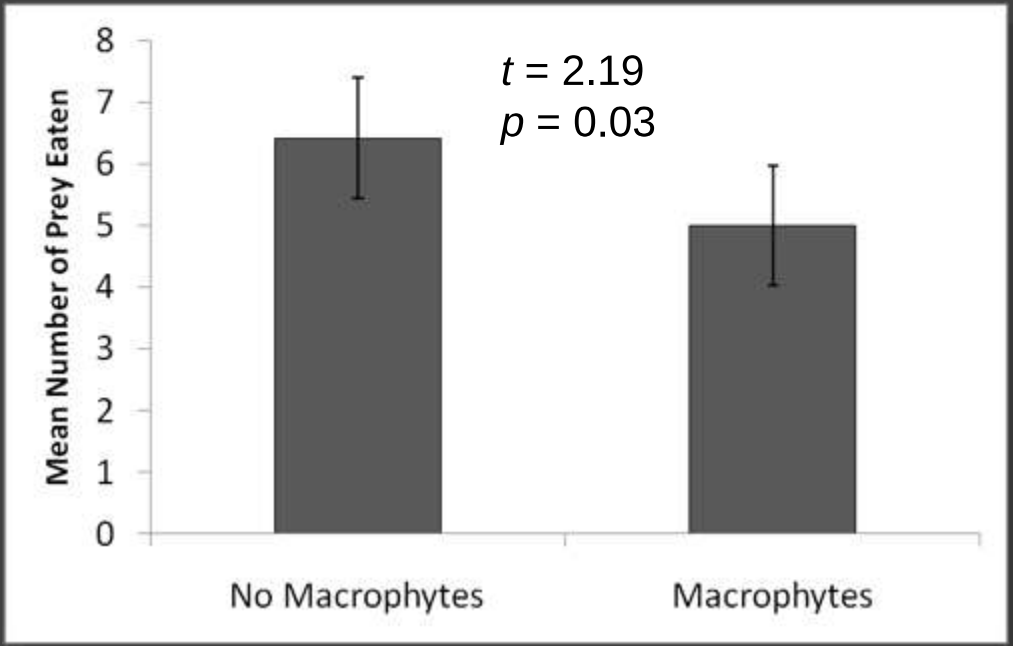
	Number of Brine Shrimp Eaten	
Trial 1	Plant	No Plant
Trial 2	10	8
Trial 3	1	1
	9	10
Mean	6.7	6.3

	Number of Brine Shrimp Eaten	
	Plant	No Plant
Trial 1	2	7
Trial 2	3	10
Trial 3	1	1
Trial 4	1	4
Trial 5	1	10
Trial 6	5	5
Trial 7	1	5
Trial 8	9	10
Trial 9	10	8
Trial 10	6	6
Trial 11	9	6
Trial 12	6	6
Trial 13	5	3
Trial 14	6	7
Trial 15	3	0
Trial 16	5	0
Trial 17	5	8
Trial 18	0	7
Trial 19	6	10
Trial 20	0	9
Trial 21	4	8
Trial 22	7	7
Trial 23	7	8
Trial 24	0	7
Trial 25	9	7
Trial 26	5	5
Trial 27	7	8
Trial 28	8	8
Trial 29	6	6
Trial 30	10	10
Trial 31	8	10
Mean	5.0	6.6

Statistics for Sophomores (Yes! 10th Graders can do this!)

Whenever we are doing a lab activity where we are comparing two treatment means students can:

- quantify experimental error by calculating variance and standard deviation
- show uncertainty regarding the means on bar graphs with 95% CI error bars
- Analyze the data with a *t*-Test
- determine the probability that the null statistical hypothesis ($mean_1 = mean_2$) is valid by calculating the *p*-value

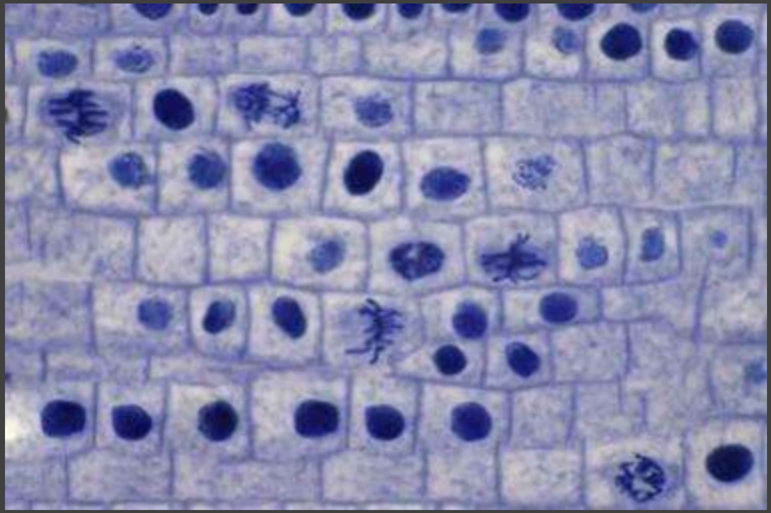


Statistics for Sophomores (Yes! 10th Graders can do this!)

Whenever we are doing a lab activity where we are comparing expected to observed outcomes for categorical data students can:

- analyze the data with a Chi-square Test
- determine the probability that the null statistical hypothesis (observed distribution = expected distribution) is valid by calculating the *p*-value

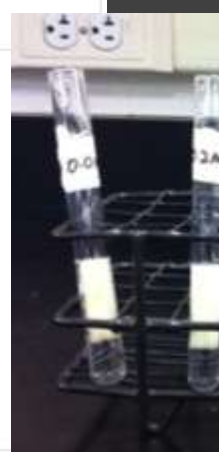
- *Note: many teachers think that the Chi-square Test was invented to analyze Mendelian probabilities. It is important to introduce the Chi-square test with non-genetics data so that students think of the test as just another tool in their tool box for analyzing particular types of data.*

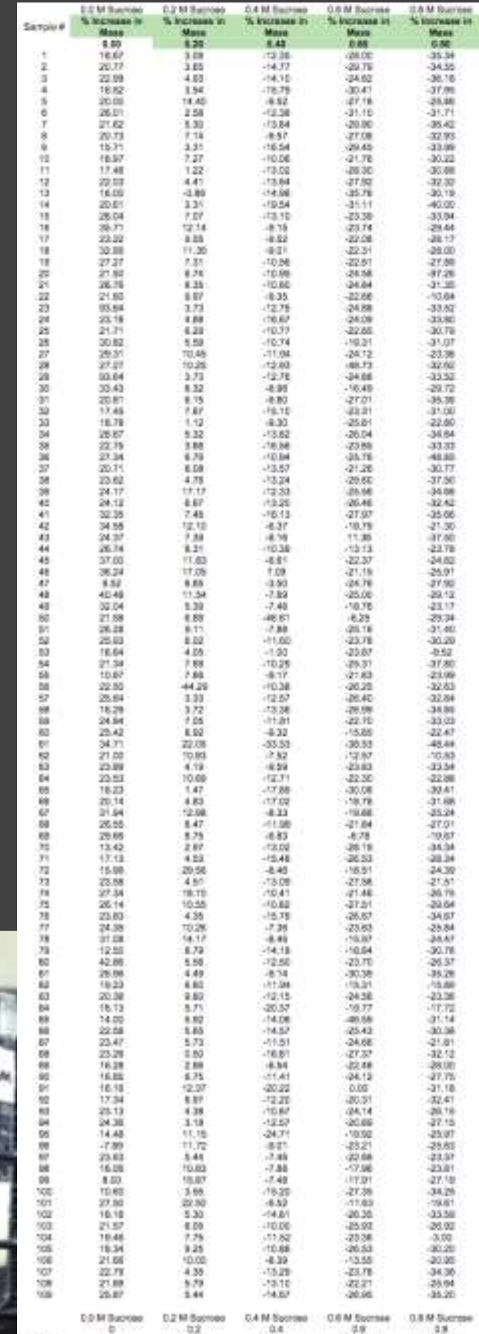


Cat	Obs	Exp	Chi-Sq
I	2222	2363	8.41
P	371	162	268.45
M	91	37	78.76
A	55	31	17.91
T	108	253	83.42
		Sum Chi-Sq	456.95

Statistics for Sophomores

	0.0 M Sucrose	0.2 M Sucrose	0.4 M Sucrose	0.6 M Sucrose	0.8 M Sucrose
Sample #	% Increase in Mass	% Increase in Mass	% Increase in Mass	% Increase in Mass	% Increase in Mass
	0	0.2	0.4	0.6	0.8
1	16.52	8.85	-3.50	-8.74	-12.92

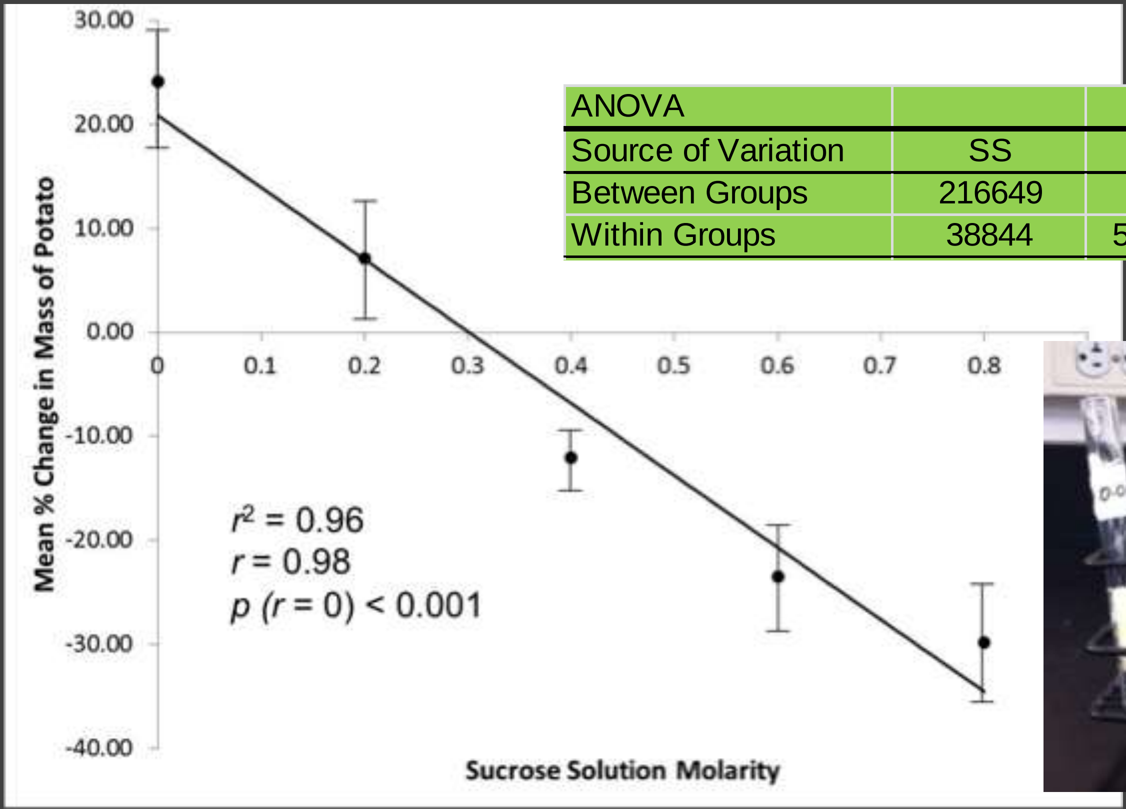




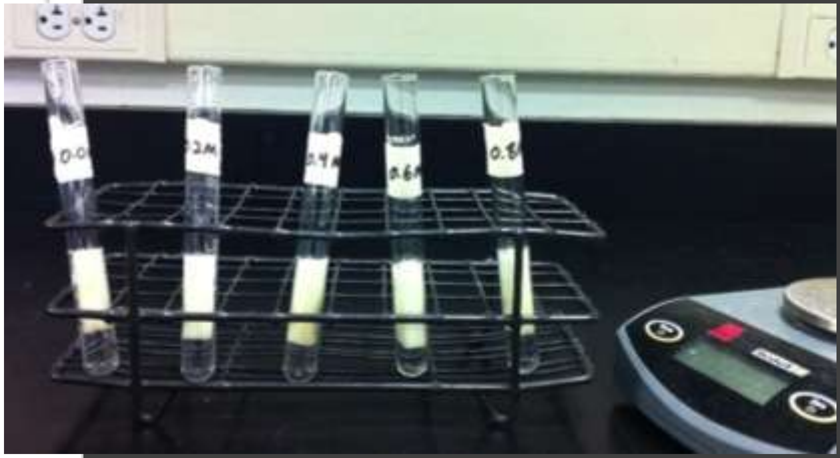
Statistics for Sophomores (Yes! 10^{th} Graders can do this!)

Whenever we are doing a lab activity where we are comparing more than two treatment means (looking for a treatment effect) students can:

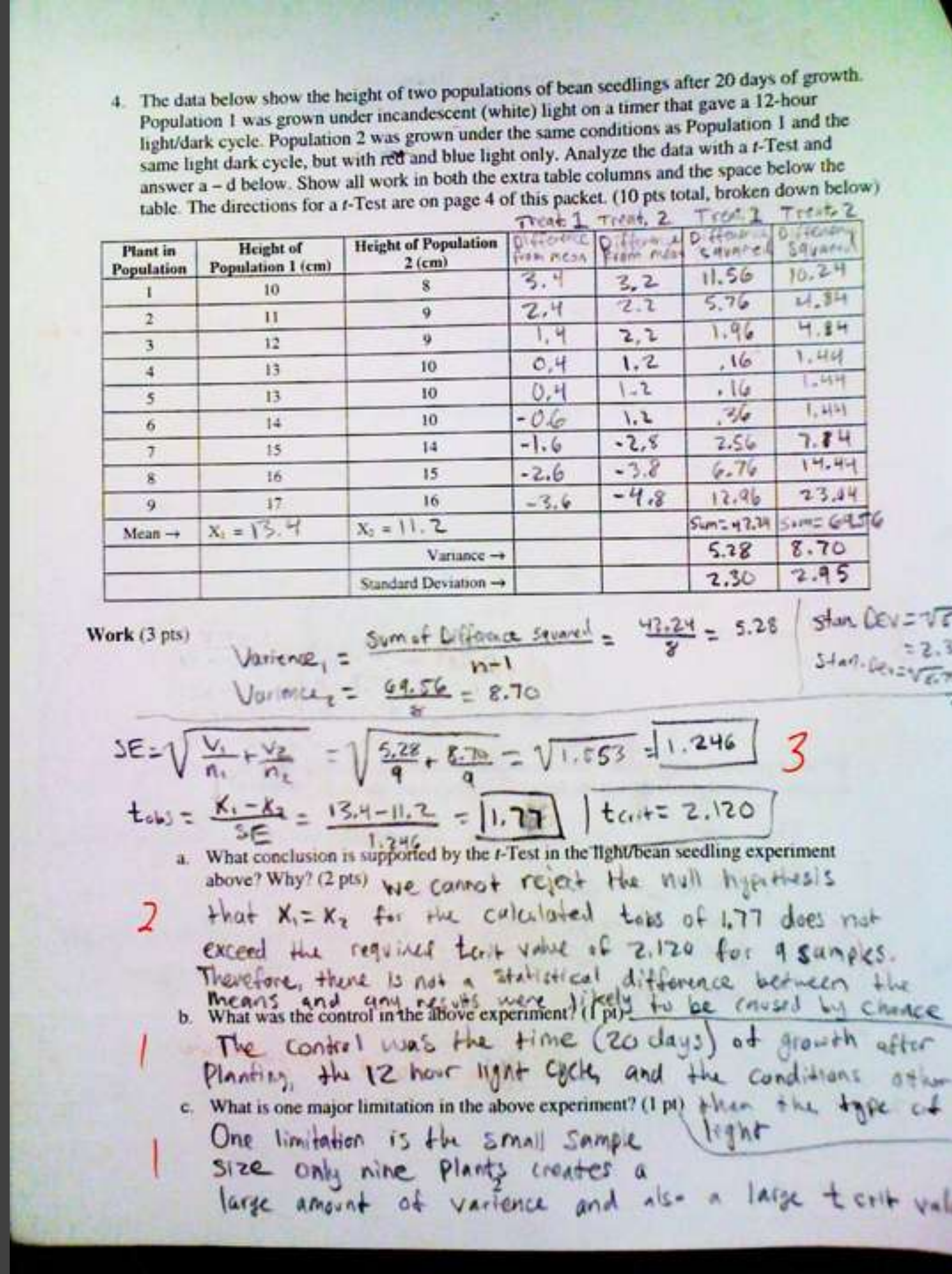
- quantify experimental error by calculating variance and standard deviation
- show uncertainty regarding the means on bar graphs with 95% CI error bars
- Analyze the data with an ANOVA (analysis of variance) Test
- determine the probability that the null statistical hypothesis ($mean_1 = mean_2 = mean_3$…etc.) is valid by calculating the *p*-value



ANOVA						
Source of Variation	SS	df	MS	F obs	F crit	*p*-value
Between Groups	216649	4	54162	753.0	2.4	< 0.001
Within Groups	38844	540	72			



What does assessment of statistics look like?



4. The data below show the height of two populations of bean seedlings after 20 days of growth. Population 1 was grown under incandescent (white) light on a timer that gave a 12-hour light/dark cycle. Population 2 was grown under the same conditions as Population 1 and the same light dark cycle, but with red and blue light only. Analyze the data with a *t*-Test and answer a – d below. Show all work in both the extra table columns and the space below the table. The directions for a *t*-Test are on page 4 of this packet. (10 pts total, broken down below)

Plant in Population	Height of Population 1 (cm)	Height of Population 2 (cm)	Treat 1 Difference from mean	Treat. 2 Difference from mean	Treat 1 Difference squared	Treat 2 Difference squared
1	10	8	3.4	3.2	11.56	10.24
2	11	9	2.4	2.2	5.76	4.84
3	12	9	1.4	2.2	1.96	4.84
4	13	10	0.4	1.2	.16	1.44
5	13	10	0.4	1.2	.16	1.44
6	14	10	-0.6	1.2	.36	1.44
7	15	14	-1.6	-2.8	2.56	7.84
8	16	15	-2.6	-3.8	6.76	14.44
9	17	16	-3.6	-4.8	12.96	23.04
Mean →	X_1 = 13.4	X_2 = 11.2			Sum = 42.24	Sum = 69.56
		Variance →			5.28	8.70
		Standard Deviation →			2.30	2.95

Work (3 pts)

$$\text{Varience}_1 = \frac{\text{Sum of Difference squared}}{n-1} = \frac{42.24}{8} = 5.28$$

$$\text{Varience}_2 = \frac{69.56}{8} = 8.70$$

$\text{Stan Dev} = \sqrt{5.}$ ... $= 2.30$

$\text{Stan. Dev} = \sqrt{8.7}$ ...

$$SE = \sqrt{\frac{V_1}{n_1} + \frac{V_2}{n_2}} = \sqrt{\frac{5.28}{9} + \frac{8.70}{9}} = \sqrt{1.553} = 1.246$$

3

$$t_{obs} = \frac{X_1 - X_2}{SE} = \frac{13.4 - 11.2}{1.246} = 1.77 \quad t_{crit} = 2.120$$

a. What conclusion is supported by the *t*-Test in the light/bean seedling experiment above? Why? (2 pts) We cannot reject the null hypothesis that $X_1 = X_2$ for the calculated t_{obs} of 1.77 does not exceed the required t_{crit} value of 2.120 for 9 samples. Therefore, there is not a statistical difference between the means and any results were likely to be caused by chance

2

b. What was the control in the above experiment? (1 pt) The control was the time (20 days) of growth after planting, the 12 hour light cycle and the conditions other than the type of light

1

c. What is one major limitation in the above experiment? (1 pt) One limitation is the small sample size only nine plants creates a large amount of varience and also a large t crit value

1

What does assessment of statistics look like?

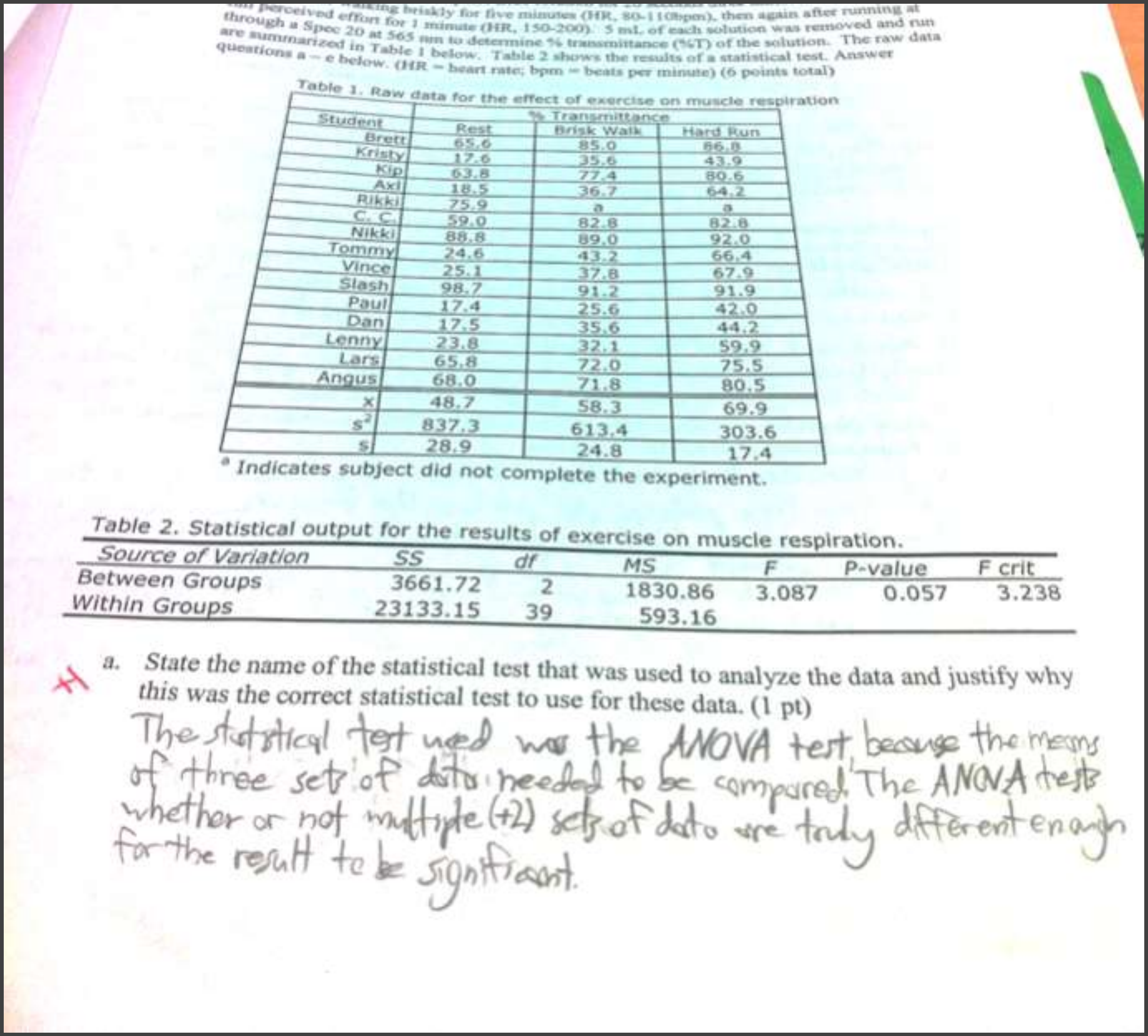

... walking briskly for five minutes (HR, 80-110bpm), then again after running at ... perceived effort for 1 minute (HR, 150-200). 5 mL of each solution was removed and run through a Spec 20 at 565 nm to determine % transmittance (%T) of the solution. The raw data are summarized in Table 1 below. Table 2 shows the results of a statistical test. Answer questions a – e below. (HR = heart rate; bpm = beats per minute) (6 points total)

Table 1. Raw data for the effect of exercise on muscle respiration

Student	% Transmittance		
	Rest	Brisk Walk	Hard Run
Brett	65.6	85.0	86.8
Kristy	17.6	35.6	43.9
Kip	63.8	77.4	80.6
Axl	18.5	36.7	64.2
Rikki	75.9	a	a
C. C.	59.0	82.8	82.8
Nikki	88.8	89.0	92.0
Tommy	24.6	43.2	66.4
Vince	25.1	37.8	67.9
Slash	98.7	91.2	91.9
Paul	17.4	25.6	42.0
Dan	17.5	35.6	44.2
Lenny	23.8	32.1	59.9
Lars	65.8	72.0	75.5
Angus	68.0	71.8	80.5
$\bar{x}$	48.7	58.3	69.9
s^2	837.3	613.4	303.6
s	28.9	24.8	17.4

[a] Indicates subject did not complete the experiment.

Table 2. Statistical output for the results of exercise on muscle respiration.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3661.72	2	1830.86	3.087	0.057	3.238
Within Groups	23133.15	39	593.16			

+1 a. State the name of the statistical test that was used to analyze the data and justify why this was the correct statistical test to use for these data. (1 pt)

The statistical test used was the ANOVA test, because the means of three sets of data needed to be compared. The ANOVA tests whether or not multiple (+2) sets of data are truly different enough for the result to be significant.

What does assessment of statistics look like?

c. Given the results of the statistical test, what conclusion can the students make about their *experimental hypothesis*? Justify your answer with data. (2 pts)

2pts

The students cannot reject the null hypothysis becase F_{obs} (3.087) is less than F_{crit} (3.238). Also, the probability (P) that the null is correct is 0.057 (5.7%). The probability must be less than 0.05 (5%) In order to reject the H_0. The students collected the data by chance.

d. Describe the control group in the above experiment. (1 pt)

1pt

The control is the % transmittance after blowing into the Bromothymal Blue Solution for 20 seconds.

e. Propose one evidence-based explanation for the outcome of the experiment. (1 pt)

1pt

The students may not have exercised as hard as others because the % transmittance is almost the same for Brisk walk & hard run (Slash, C.C., Brett)

What are the graduates saying?

- Soyeun at Dartmouth: "Knowing statistics makes it easier to assess the credibility of research."
- Evan at Wash U.: "It's quite easy now to dismiss studies and evidence because of a high margin of error or small sample size."
- Lulu at American: "Simply put, learning statistics in high school biology really just helped overall in providing a sharper grasp of critical thinking and analysis that can be applied in myriad aspects."
- Claire at U. of Colorado: "Learning statistics definitely gave me an advantage in my college biology classes. Understanding the applications and meanings of the different tests helped me a lot because we have to do a lot of higher level critical thinking, and it is considerably easier knowing the mechanics and implications of the tests."
- Nate at Trinity: "I've found the knowledge of statistics I was given in HS Biology to be absolutely essential in the physics labs I have done thus far. While I also took a statistics class in high school, I don't think I really retained any of that."
- Nina at U. of Miami: "I found that learning statistics and specifically how statistics apply to sciences in high school biology was essential to college understanding. Primarily, it helped me to better read and understand scientific papers. But it also put me ahead of the curve--many if my peers still do not understand how to properly use a t-test."
- Ved at Harvard: "It's irresponsible to not teach statistics in biology. Many of the common misconceptions that are held by large numbers of people in the United States stem from not understanding how data are interpreted to draw conclusions that end up affecting our day-to-day lives. Teaching statistics is a good place to start fixing this widespread problem.

Where to find these resources:

- www.fairviewhs.org/staff/paul-strode
- Paul Strode: paul.strode@bvsd.org

Thank you for coming!