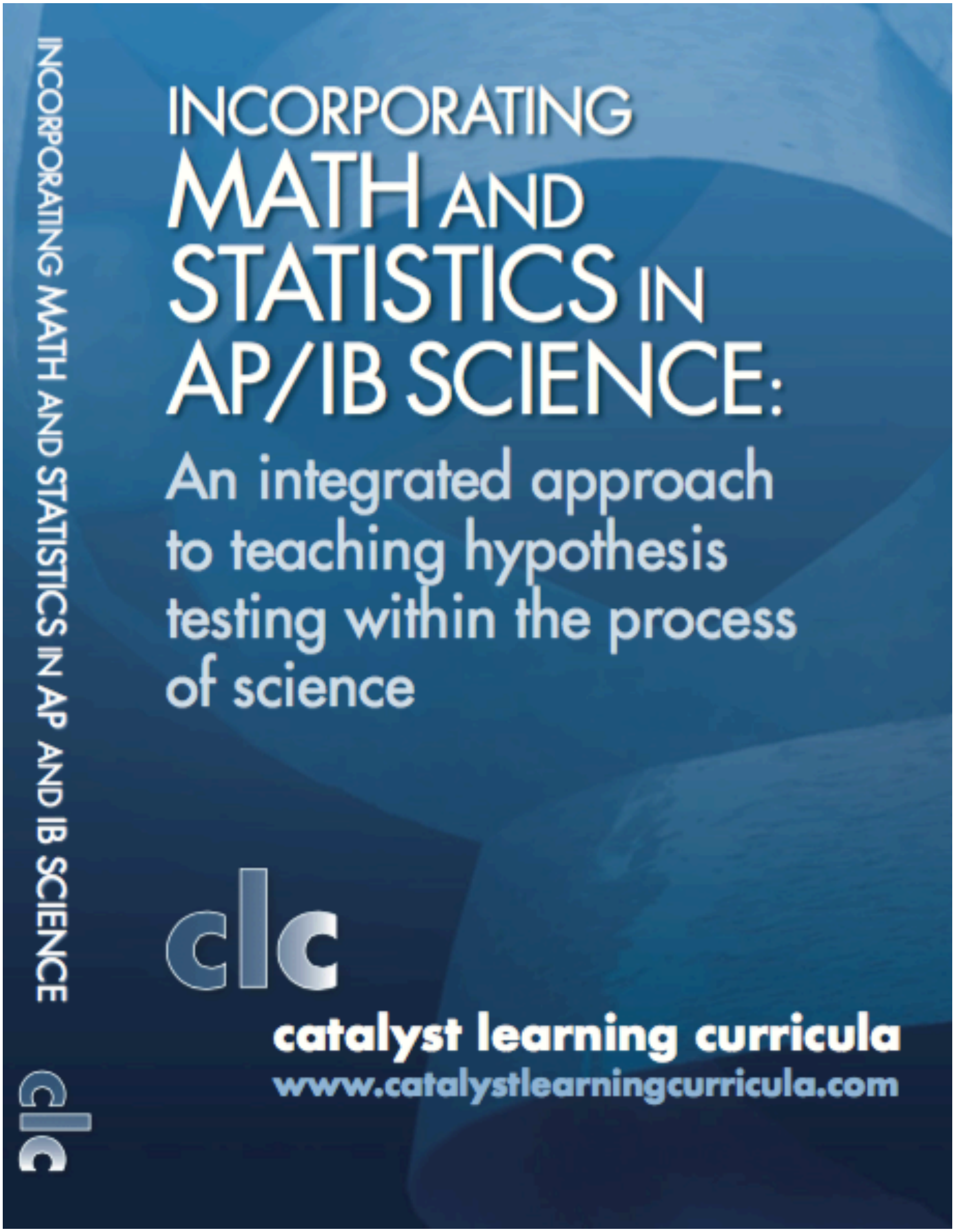
INCORPORATING
MATH AND
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AP/IB SCIENCE:
An integrated approach
to teaching hypothesis
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INCORPORATING MATH AND STATISTICS IN AP/IB SCIENCE:

14 NGSS-based experiential, higher-order thinking activities for Advanced Placement* (AP), International Baccalaureate** (IB) high school or college students, covered in ~20-22 class periods

Evidence-supported conclusions depend on data collected and analyzed in a manner consistent with the scientific method. This curriculum gives teachers an efficient and effective approach for building students' math skills and teaching the use of statistics while covering content topics in biology and ecology. Review of significant figures, precision, accuracy, uncertainty, graphing and graph interpretation is laid out in the initial activities to fortify students' mathematical knowledge base. Process of science concepts are introduced in sequential order, with students learning how to choose an appropriate graph, determine the best sample size, select suitable descriptors of central tendency, write a null hypothesis and express mathematical error. Calculations for variance, standard deviation, standard error of the mean and the 95% confidence interval are covered with step-by-step examples that help students understand the source of each number. Students learn how to choose the correct statistical test to perform with different types of data, practicing chi-squared, Pearson's Test of Correlation and the Student's t-test, using easy-to-follow directions and specific applications.

In the culminating activities, students will develop advanced skills that cross over into applied math: using online databases for original scientific research; designing data-based graphic organizers and schematics; writing mathematical equations from models and simulations; and designing formulas on spreadsheets or customized computer programs for data-generating models. Whether your students are fulfilling the Next Generation Science Standards in a general level course, writing Internal Assessments for the IBDP, or preparing for an AP or IB exam, this curriculum is a complete unit for teaching math and statistics as utilized in advanced high school and college-level science.

This curriculum was specifically designed to provide an introduction to the following content areas required by the Advanced Placement College Board and the International Baccalaureate Diploma Programme courses in biology and environmental science:

- Soil Nutrients
- Mitotic Cycle and the Mitotic Index
- Human Impact on the Environment
- Population Dynamics
- Hardy-Weinberg Allele Frequency Equilibrium
- Protein Sequence Cladistics
- Infectious Disease Propagation

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Incorporating Math and Statistics in AP/IB Science

Table of Contents

(This sample contains Activity 2, 8 and 11 only, which do not correspond with the page numbers listed below. The full curriculum can be purchased at the Catalyst Learning Curricula website)

Incorporating Math and Statistics in AP/IB Science

Activity Two: Identifying Strengths and Weaknesses of Commonly Used Data Descriptors

Teaching time: 1-2 class periods of 50 minutes each

Objectives:

a) For students to understand the difference between normally distributed data and data that does not fit a normal Gaussian or bell-shaped distribution pattern.
b) For students to recognize the utility of parameters that can be used to describe data.
c) For students to learn how to choose the best parameters of central tendency to describe a data set.
d) For students to broaden their ideas about what parameters or central tendency descriptors they may choose.
e) For students to make conjectures and take calculated risks.

Materials:

For each student: a notebook for jotting down ideas and taking notes, one metric ruler, one calculator and one sheet of graph paper. For each group of 2-4 students: eight cat toys in the shape of a mouse, each with tails that have been modified per the instructions in Step 1 below, and two bowls, baggies or other containers, each to hold four of the mouse-shaped toys (see Step 4 below). Optional: if you have small animal cages, two water dispensers and food bowls to help create a convincing-looking experimental setup. For the class: one shared spreadsheet for collected data on mice tail measurements (see Step 6).

Procedure:

1. Prior to class, if you search “mouse cat toys” online, you can find a bulk supplier and pay a relatively inexpensive amount for a large quantity. Divide the toy mice in half to form two groups with an even number of mice in each group. Trim the tails on the mice in each group to make the mean tail length nearly identical for the two groups (the mean tail length in the first group should equal the mean tail length in the second group), however, you want all of the mice in the first group to have nearly identical tail length, and you want the mice in the second group to have two different tail lengths—some quite long and some quite short. Here is how to accomplish this:
    a. Make a quick estimate of the mean tail length of all the toy mice purchased by measuring the tails on about half of the toys. Use this number as the estimated mean tail length for the next step.

b. Calculate the length of a tail that would be 1/3 the estimated mean length and calculate the length of a tail that would be 2/3 the estimated tail length. For example, if the mean tail length of all the toys is estimated to be ~6 cm, then 1/3 the estimated mean tail length would be 2 cm and 2/3 the mean tail length would be 4 cm.
c. Divide the toys into two groups, each with an equal number of toys, but be sure all the toy mice in the first group have a tail that is at least as long as the mean tail length of the group and place all toys with the longest or shortest tails in the second group.
d. For the first group, trim the tails on all the toy mice such that all toys in this group have a tail that is 2/3 the length of the estimated mean tail length with only +/- 0.2 cm of variation. In the example given above, all the mice in this group would have their tails trimmed to 4.0 cm (+/- 0.2 cm).
e. For the second group, trim the tails on all the toys such that half the toys in this group have tails that are 1/3 the length of the estimated mean tail length (+/- 0.2 cm) and the other half of the toys in this group have tails that are very close to the estimated mean tail length. For the example given above, this group would have mice with tails that are either 2.0 cm (+/- 0.2 cm) or 6.0 cm (+/- 0.2 cm).
f. After all the mouse tails have been trimmed, the mean for each group should be nearly equal. For the example given above, the mean tail length for the first group and the second group is now 4.0 cm (+/- 0.2 cm).

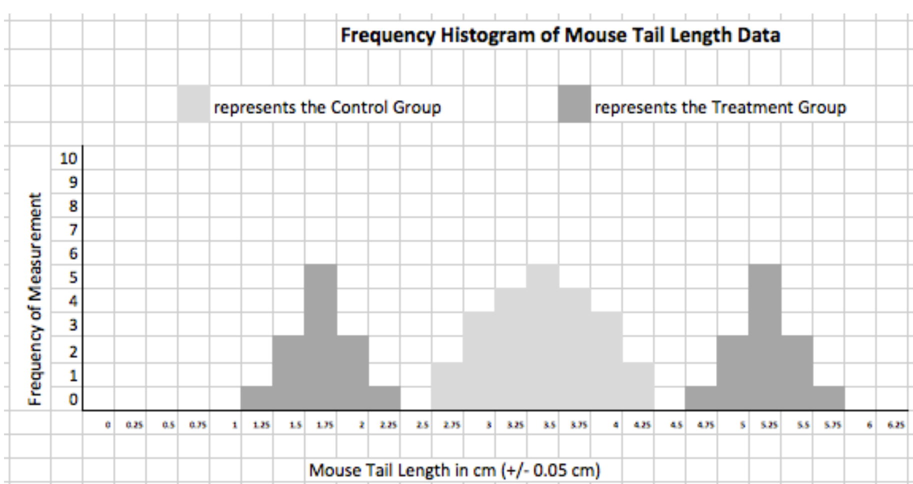
2. If you have small animal cages in your classroom, place the mice from the first group all in the same cage and place the mice from the second group in a separate cage. Add a bottle of water and a dish of food to each cage to help make it a convincing experimental set-up. Label the first cage "Control Group" and label the second cage "Treatment Group."
3. When the students arrive, explain that you have been conducting an experiment to determine the impact of a particular mutagen on gene regulation. Show the students a mouse from the first cage, holding it up by its tail, and let the students know that the mice in this cage are in the control group and no mutagen was added to their food supply. Hold up a mouse from the second group and let the students know that the mice in this cage are in the treatment group and they have had a mutagen added to their food supply from weaning until now. Tell the students that it appears that the mutagen may have impacted the gene that regulates tail growth, but you are not sure if there is a measurable difference.
4. Divide the students into groups of 2-4 (depending on the number of toy mice you have) and ask that a representative from each group retrieve four mice from each cage, as well as rulers and graph paper, to bring back to their group. Allow the students to each use a marked or colored bowl, baggie or other container to keep the mice from the control group separate from the mice in the treatment group.

5. Ask the groups to each measure the tails of the mice and tabulate the mean tail length for mice in each group. If you have not already done so, this is a good time to review precision in measuring so all students use the same number of significant figures and uncertainty for their measurements. Here is a quick review to cover with your students:
    a. If at all possible, measurements should include one digit beyond the markings on the instrument being used. For example, if the students are using a metric ruler that has increments for millimeters on the minor scale, then the measurement that is one digit beyond the millimeter marking would be the hundredths place if an estimate of that place value is visible to the student. Ultimately the person measuring must decide the level of uncertainty for their own measurements.
    b. Because the data point with the lowest number of significant figures will limit all collected data to that number of significant figures, one measurement can result in a loss of data for all other groups.
    c. Researchers conducting the same experiment must agree upon the measuring technique if data will be compiled or compared. For example, there should be a discussion of the correct starting point on the tail, in which the exact placement of the ruler is determined, as well as a consensus regarding the ending point on the tail. (Will the students measure from the top or bottom of the mouse? Will they include the fur on the tail? etc.)

	A	B	C
1		Mice Tail Length in cm	
2			
3		Control Group	Treatment Group
4		No Tx	Tx
5			
6	Group 1	3.25	1.25
7		3.75	2.00
8		3.50	5.00
9		4.00	4.75
10	Group 2	4.00	5.75
11		3.25	1.50
12		3.50	2.00
13		3.50	5.00
14	Group 3	3.00	5.25
15		3.00	5.50
16		3.75	2.25
17		3.75	1.75
18	Group 4	3.00	5.25
19		3.25	5.25
20		3.50	1.75
21		3.25	1.75
22	Group 5	3.50	5.00
23		3.50	5.00
24		2.75	1.75

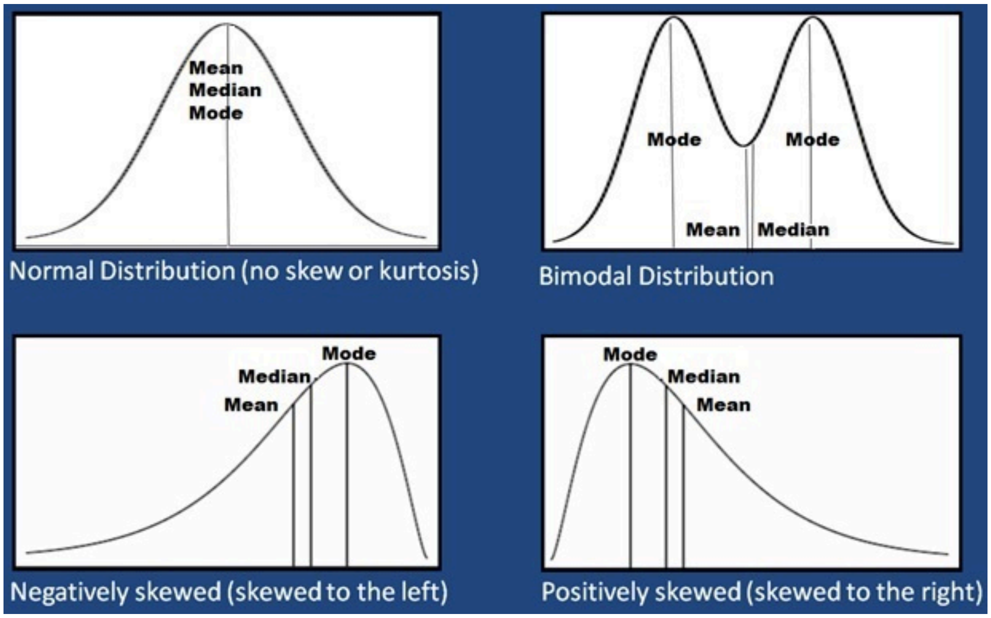
6. Ask the students to report their measurements on a shared spreadsheet (see the example spreadsheet, above right).
7. Ask the students to calculate the mean or use a formula on the spreadsheet to calculate the mean automatically.
8. Ask the students to make five written observations in their notes comparing the mean of the control group to the mean of the treatment group. It will be easy for the students to write 1-2 observations. However, pushing them to write 4-5 observations will force them to think beyond the most obvious ideas. Spot check work recorded in the students' notebooks so they are compelled to complete this type of low risk formative work now and for each of the activities that follow in this curriculum.
9. Remind the students that the mean is a descriptor of central tendency, or a way to describe data that is normally distributed. Explain that the mean is not "raw data," only the measured data points are considered to be "raw data." Instead the mean is a common form of anaylsis that can be used to describe this data set.

10. Ask the students if they think the mean is a good description of central tendency for this data set. If another scientist were not given the raw data but only saw the mean for each group, would the mean accurately reflect the data? *(The students will likely point out that the means are nearly identical, but the mice in the treatment group differed from the mice in the control group.)*
11. Ask the students to think of other possible parameters or data descriptors. Give them time to think of and talk about descriptors such as minimum, maximum, range, median, mode, etc. Ask the students to define each of the descriptors of central tendency they mention.
12. Ask the students to each silently decide for themselves which descriptor they think would be best to describe the raw data set. Ask them to record their choice in their notes and defend it using an explanation that includes their raw data.
13. Ask the students to each share their choice with their group and discuss any differences.
14. Draw a bell-shaped curve on the board and explain that the shape of this curve is what statisticians call a Gaussian distribution or "normal distribution." Let the students know that this distribution pattern is what is expected when all members of a population (called "N") are measured for a trait where measurements fall around the mean. The mean for an entire population, "N," is called mu (μ), which is different than the mean for a sample of the population called, "x bar" (written as an x with a bar over it).
15. Give a familiar example of a data set that would have a normal distribution such as human height, body temperature or life span. Ask where the mean would fall in the example and ask the students why some data points would fall above or below the mean.
16. Ask the students to make a rough graph of each data set (on separate graphs or together), using any type of graph they choose. Below is a histogram of both the control group and the treatment group for reference (do not share this graph; ask the students to share the ones they've made).



17. Ask the students to display the graphs they made, then have them walk around the room to review the different variations created by their peers.
18. Ask the students to write 4-5 conclusions about the two distribution diagrams that were created from the class data. After all students have written conclusions in their notes, ask them to share their observations within their small groups.
19. Ask the students what can be said about the distribution of the mouse tail data? *(They should observe that the control group has a normal distribution but the treatment group is bimodal.)* The students may not be familiar with the term bimodal, so it would be good to discuss this term as a class.
20. Ask the students why the distribution is oddly shaped. *(They should point out that the tails were either long or short, and this caused two separate data groups to form within the treatment group data set.)*
21. Ask the students to indicate where the mean would be on the graphs for each data set. Ask a follow-up question each time they indicate where the mean would fall: "Is the mean a good descriptor of the central tendency of this data set?" *(The mean is a good descriptor for the control group since all the data falls just above or below the mean in a normal distribution. However, the mean is not a good descriptor for the treatment group since the treatment data falls into two groups well above and well below the mean.)*
22. Ask the students where the median would fall on the graphs for each data set. Ask the students if the median would be a better descriptor for these data sets. *(The median is a good descriptor for the control group since all the data falls just above or below the mean in a normal distribution. However, the median is not a good descriptor for the treatment group since the treatment data falls into two groups well above and well below the median.)*
23. Ask the students where the mode would fall on the graphs for each data set. Ask the students if the mode would be a better descriptor for these data sets. *(The mode is a good descriptor for the control group since all the data falls just above or below the mean in a normal distribution. However, the mode is not a good descriptor for the treatment group since it will fall either with the low or the high data group.)*
24. Ask the students where the range would fall on the graphs for each data set. Ask the students if the range would be a better descriptor for these data sets. *(The range is a good descriptor for both the control and the treatment group since it gives an indication that the data is cohesive for the control group and spread out for the treatment group.)*
25. Ask the students to draw 4-5 other diagrams of distributions in which mean would not be a very good descriptor for the data collected (see some example images below).
26. Ask the students to indicate the theoretical location of the mean, median, mode, minimum and maximum on each distribution diagram they draw. Some examples are given below to guide you. Do not give these examples

to the students. Instead, lead them to discover the information through their own thinking and paired discussions.



D'Avello, Tom, and Sephen Roecker. "Chapter 4 – Exploratory Data Analysis." *Statistics for Soil Survey*. March 1, USDA, 2017.

27. Make a chart on the board to record the strengths and limitations of the central tendency descriptors discussed in this activity, then ask the students to supply information to fill the chart. You may end up with a chart that looks something like the one shown below. Do not simply give the students this information or ask them to look for ideas online. Make them discover it by asking leading questions or have them work in pairs to mull over one aspect or another of the chart until they make their own determinations. The example of the mouse tail data set serves to reveal the limitations of each descriptor.

	Strengths	Weaknesses
Mean	• Is commonly used and well understood • Is a good summary of data that is normally distributed • Uses all data points	• Implies a normal distribution • Does not describe any specific data point • Does not reveal bimodal or skewed distributions • Can be greatly impacted by outliers
Median	• Is commonly used and well understood • Uses an actual data point to describe data (if there are an odd number of data points) • Not greatly impacted by outliers	• Implies a normal distribution • Does not reveal bimodal distributions • Does not indicate the degree of variation in the data set • Does not use all the data in the set

Mode	• Is commonly used and well understood • Is useful when one measurement is very common • Hints at bimodal or atypical distributions • Not greatly impacted by outliers • Can be used with non-numerical data	• Does not reveal the degree of variation • There may be more than one mode or none at all • Does not use all the data in the set
Range (Min. - Max.)	• Is commonly used and well understood • Reveals outliers • Indicates the degree of variation	• Does not reveal the clustering of data

28. Typically the mean is an excellent descriptor for a normal distribution but it is not as useful for data that lacks a normal distribution. In the case of data that is not normally distributed, the scientist is better off using other parameters that will be discussed in the next activity or using a graphic representation of the data. Discuss these points briefly and consider using a follow-up assignment for homework to determine how much your students understand from this activity. Additionally, to analyze a set of data using a statistical test, it must frist be confirmed to have a normal distribution.
29. To confirm that the skills from this lesson have been acquired and can be applied independently, ask the students to do the following homework:

Application-based Homework:

Ask the students to generate a fake data set for a particular measurement that they think would have a normal distribution in a sample population. Ask them to use an original example that has not been used in class or by their peers. Ask them to draw the expected distribution pattern with the mean, median, mode, minimum and maximum clearly indicated.

In addition, ask the students to generate a fake data set for a particular measurement that they think would not have a normal distribution in a sample population. Ask them to use an original example that has not been used in class or by their peers. Ask them to draw the expected distribution pattern with the mean, median, mode, minimum and maximum clearly indicated, and have them explain why certain data points diverge from the normal distribution curve.

Activity Eight: Applying Chi-squared and Pearson's Correlation Analysis to Test a Hypothesis (While Teaching the Phases of Mitosis and the Mitotic Index)

Teaching time: 2 class periods of 50 minutes each

Objectives:

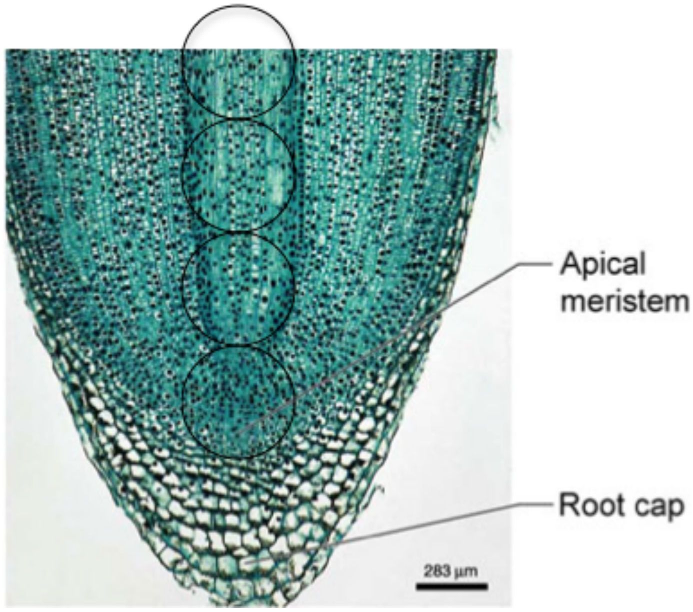
a) For students to review the parts of the microscope and its proper use.
b) For students to observe and identify cells in various stages of the cell cycle.
c) For students to analyze the data they collect using chi-squared test and Pearson's test of correlation.

Materials:

For each student: one copy of the "Root Tip Cell Cycle Data Analysis" handout that follows this lesson plan. For each pair of students: one light microscope and one prepared onion root tip slide or similar sample of cells in mitotic division.

Procedure:

1. Prior to class, review the *Teacher's Version* of the data analysis for this lab using the pages that follow titled, "Root Tip Data Analysis." This example data set will not be the data that your students collect but instead an example of how to process the data collected and how to work through each step of the two hypothesis tests that are being taught in this lesson. Performing the example calculations prior to class will allow you to answer questions more easily during class while the students complete their own data collection and analysis. You may also want to project or share digitally the image on the next page, to show the students an approach for collecting their mitotic index data at the appropriate location on the roots. The black circles represent the ocular field with the first field set just above the root cap. If the students are unable to locate 100 cells within a single ocular field, they may move the ocular field laterally while remaining at the same distance from the root cap to reach a 100 cell count.



2. If possible, prior to class, share a class data collection spreadsheet. For example, you can create a Google Spreadsheet and share it with all of the students in the class using Google Drive, allowing students editing privileges so they can input their data during class time. Include several copies of the "My Raw Data Chart of Root Tip Cell Cycle Counts" found at the bottom of the first page of the student handout so each student or each pair of students has a place to add their collected data during class. With access to this shared spreadsheet, students will be able to add their name and data to a chart, then use the collections made by other students to compile the class data for Part 1 and Part 3 of the student handout.
3. This activity lends itself to an extension experiment that students can design and carry out themselves in Step 6 of the student handout. If you choose to do it, you will need to purchase pearl onions, garlic or other bulbs and allow them to grow root tips under the influence of a chosen treatment. Root tips can be grown by suspending dry bulbs root side down on three toothpicks with the root ends covered in a few millimeters of water. Roots will take 3-7 days to emerge. Roots can be trimmed and treated with a nucleic acid stain such as Feulgen or acetocarmine. Look up "how to" videos on use of these stains if the process is not familiar and practice prior to class to ensure you can adequately guide the students through their self-designed experiments. For treatment, students may want to use fertilizers, nicotine, caffeine or other stimulants, protease chemicals or other mitosis inhibition agents such as UV radiation, vinca alkaloids, etc. Avoid known spindle or DNA mutagens such as colchicine or ethidium bromide, and do the research needed to become fully aware of safety considerations.
4. Allow students to follow the steps in the handout, counting cells in different phases of the cell cycle using prepared slides and contributing their data to a group data chart for all others to record. Students may find it more accurate to perform cell counts from photos taken with their phone through

the ocular lens because they can increase the magnification and mark off counted cells using a photo paint or edit program. If phase identification is new or difficult for your students, they can get practice before beginning this activity using the “Onion Root Tips” tutorial program and photos on the University of Arizona Biology Project website (www.biology.arizona.edu).

5. Realize that the relevance of counting cells undergoing mitotic division may not be very clear to students when using root tips. However, you can connect this activity to cell counts of dividing cells used to diagnosis disease, which may have more relevance. For example, a biopsy is a common medical procedure used to compare the observed mitotic index to the expected mitotic index for a given tissue type. Different tissues have different expected rates of mitosis, just as the different parts of the root tip have different expected rates of mitosis. The method the students are using is similar to some cancer screenings that use mitotic indices to determine if cells are growing more rapidly than expected.
6. Use this activity to review and reinforce the purpose of the null hypothesis as a falsifiable statement that can be tested using statistical methods by ensuring the students are able to write a conclusion statement from their chi-squared and Pearson’s correlation results. Example statements are given in the *Teacher’s Version* for the example data set provided.
7. Detailed steps are provided for both types of data anyalysis in the student handouts and in the example data set rather than in this part of the lesson plan so that you can jump right into the mitotic index activity when class begins.
8. Appendix A (at the end of this curriculum) contains a more extensive chi-squared critical values table which you may choose to share with the students. The student handout contains an abbreviated version of this table that will suffice for the degrees of freedom used in this activity.
9. Appendix C (at the end of this curriculum) contains a summary of the parameters and hypothesis test equations. Although not all hypothesis tests will be introduced in this activity, you may choose to share a copy of this summary at the start of this activity so the students begin to use it as a reference.
10. The number of data points used to teach chi-squared and Pearson’s correlation are intentionally small so that all calculations can be performed by hand. Although this is not a good example of a robust sample size, the small sample size is useful for teaching the students how to perform the algebraic steps of the two hypothesis tests. Guide the entire class through the chi-squared and test of correlation calculations as a group, so that each student is able to understand the source of each number and may even begin to understand how the numbers are impacting the outcome of the analysis.

Root Tip Cell Cycle Data Analysis

Part 1: Collection of Cell Cycle Data

1. Focus your field of vision on the lowest portion of the root tip so the round lower arc of your field of vision as seen through the ocular lens lies just above the waxy root cap.
2. Bring the magnification up to 100x and count at least 100 nucleated cells in your field of vision, deciding which stage of the cell cycle each cell is in and writing the number of cells in each phase in the appropriate box (interphase, prophase, metaphase, anaphase, or telophase). Do not count cells in which the chromosomes are either not visible or are out of focus, such that the phase cannot be determined.
3. Move the field of vision up the root so cells that were at the top of your field of vision are now at the very bottom of your field of vision, just out of sight.
4. Repeat steps 2 and 3 until you have collected data on at least 100 cells from each of four fields of vision moving progressively away from the root cap for each count.
5. Tabulate your individual data totals at the bottom of each column.
6. Share your individual data with your peers using a shared class data chart. When you calculate the class data for yourself, do not include your own data. You will be comparing your data to the class data in the next part of this activity.

My Raw Data Chart of Root Tip Cell Cycle Counts:

Phase of Cell Cycle: Field of vision:	Number of Cells in Interphase (Not in Mitosis)	Number of Cells in Prophase of Mitosis	Number of Cells in Metaphase of Mitosis	Number of Cells in Anaphase of Mitosis	Number of Cells in Telophase of Mitosis
1st field of vision above the root cap					
2nd field of vision above the root cap					
3rd field of vision above the root cap					
4th field of vision above the root cap					
Totals for each phase:					

Total number of cells counted in this data set: _________________

Class Raw Data Chart of Root Tip Cell Cycle Counts:

Phase of Cell Cycle: Field of vision:	Number of Cells in Interphase (Not in Mitosis)	Number of Cells in Prophase of Mitosis	Number of Cells in Metaphase of Mitosis	Number of Cells in Anaphase of Mitosis	Number of Cells in Telophase of Mitosis
1st field of vision above the root cap					
2nd field of vision above the root cap					
3rd field of vision above the root cap					
4th field of vision above the root cap					
Totals for each phase:					

Total number of cells counted in this data set: _______________

Part 2: Statistical Analysis of Mitotic Phases Using a Chi-squared Test

1. Using the chart below, calculate the expected number of cells in interphase and in each phase of mitosis based on the class data (you can do this by using a ratio of the total number of cells you counted compared to the total number of cells counted by the class in each phase).

Expected Number of Cells in Each Phase of Mitosis as a Ratio of the Class Data:

	Interphase	Prophase	Metaphase	Anaphase	Telophase
Total number of cells from the last row of class data set in Part 1					
Multiply the total in each square above by the total number of cells you counted and then divide by the total number of cells the class counted to predicted the expected number for each phase.	% of cells expected to be in Interphase =	% of cells expected to be in Prophase =	% of cells expected to be in Metaphase =	% of cells expected to be in Anaphase =	% of cells expected to be in Telophase =

2. Analyze your phase data against the class data for the proportion of time cells spend in each phase of mitosis. Use the class data as the “expected” count and your data as the “observed” (actual) count.

   Your null hypothesis (H_0) in this case is: There is no difference in the number of root tip cells in each phase of mitosis for my data set compared to that of the rest of the class.

   You will need to perform a chi-squared (x^2) analysis to test the null hypothesis and find out if your data are similar enough to the class data or if they are clearly different than the class data according to the $p < 0.05$ that is accepted in science. The instructions below will help guide you through this statistical test:

   The chi-squared (x^2) test is performed using the following equation:

   Chi-squared = Sum of (observed - expected)^2/expected

   or, in mathematical terms this is written $x^2 = \Sigma ((o-e)^2/e)$

   where “o” is the observed number of cells and “e” is the expected number of cells for each phase of mitosis. Important: You must use count data, not percentage data.

Chi-squared Data Analysis Helper	**Categories = Phases of the Cell Cycle**					
	Interphase	Prophase	Metaphase	Anaphase	Telophase	**Total**
Observed Cell Counts (o)						
Expected Cell Counts (e)						
Difference Squared $(o-e)^2$						
Difference Squared Divided by Expected $(o-e)^2/e$						
The chi-squared value is equal to the sum of all differences squared: $x^2 = \Sigma ((o-e)^2/e)$						

3. Using a chi-squared data table (such as the one shown below) and the degrees of freedom, determine whether or not the difference between your data and the class data is significant. Degrees of freedom would be defined as the number of possible categories minus 1. In this case there were four phases of mitosis plus interphase, so the degrees of freedom would be 5 - 1 = 4 degrees of freedom. In science, the 5% ($p < 0.05$) column is the standard to which all statistical tests are held. This data column reflects the assumption that there is a less than 5% probability of the null hypothesis being falsely rejected.

   If your chi-squared value is smaller than the number found on this chart under the 5% column and across the row from 4 degrees of freedom, then you have failed to reject your null hypothesis, meaning your data are not significantly different from the class data. If your chi-squared value is larger (than the number found on this chart under the 5% column and across the row from the 4 degrees of freedom), then you can reject your null hypothesis because the amount of time your root tips spent in mitosis is significantly different from that of your classmates or the method you used to count and categorize your cells was significantly different from the method used by your peers.

	Probability					
Degrees of Freedom	**0.90**	**0.50**	**0.25**	**0.10**	**0.05**	**0.01**
1	0.016	0.46	1.32	2.71	3.84	6.64
2	.0.21	1.39	2.77	4.61	5.99	9.21
3	0.58	2.37	4.11	6.25	7.82	11.35
4	1.06	3.36	5.39	7.78	9.49	13.28
5	1.61	4.35	6.63	9.24	11.07	15.09

4. Based on your chi-squared value, do you reject the null hypothesis or do you fail to reject the null hypothesis? Explain your response.

5. The main thing to note about the chi-squared formula is that the value of x^2 increases as the difference between the observed and expected values increases. Explain the significance of getting a chi-squared value that is higher than the number on the chi-squared value chart at the $p < 0.05$ level.

6. If desired, you could conduct an experiment in which you treat your root tips with a chemical or subject them to some environmental pressure that disrupts the amount of time the root tip cells spend in each phase of the cell cycle. An additional chi-squared analysis of your new data would reveal whether the treatment you used on the root tips results in cells spending a significantly different percentage of time in each phase of mitosis. Use the internet to research what treatments may have an impact on the cell cycle. Write an experiment with a root tip treatment that you suspect would alter the percentage of time cells spend in each phase of mitosis:

Null Hypothesis:

Independent Variable:

Dependent Variable:

Procedure:

Part 3: Statistical Analysis of Mitotic Indices Using Pearson's Test of Correlation

1. For the next analysis, you will be graphing the mitotic index against the distance from the root cap for each field of vision using coordinate points. The mitotic index (MI) is the percentage of cells in the process of mitosis divided by the total number of cells counted. The chart below will guide you through this calculation using data from Part 1 for cells counted in each field above the root cap.
2. Before you begin, calculate the diameter of the field of vision for the magnification you used in Part 1 to determine the actual distance from the root cap in micrometers or millimeters (recall that 1mm = 1000 micrometers or µm). Write the calculated distances in the first column of the chart below.
3. Calculate the mitotic index for each viewing for the class data using the 2^{nd}-9^{th} columns of the chart below. You may add your individual data to the class data

if you found no significant difference between your data compared to the class data in Part 2.

Class Data for Mitotic Index:

	Interphase	Prophase	Metaphase	Anaphase	Telophase	Total number of cells in mitosis	Total number of cells counted	MI (cells in mitosis/total cells counted *100)
1^{st} field of vision distance from root cap:								
2^{nd} field of vision distance from root cap:								
3^{rd} field of vision distance from root cap:								
4^{th} field of vision distance from root cap:								

4. Create a graph of the mitotic indices using your best scientific graphing skills with the independent variable as the x-axis and the dependent variable as the y-axis. The data in the 1^{st} column of the chart above (distance from the root cap) will be the y-coordinates for each x-coordinate in the 9^{th} column of the chart above (mitotic index).
5. Calculate the correlation coefficient (r) between the mitotic index and the distance from the root cap by performing a Pearson's test of correlation on these coordinates. The steps needed to perform this calculation follow:

   The equation used for a Pearson's test of correlation:

$$r_{xy} = \frac{\Sigma\,(x-\bar{x})\,(y-\bar{y})}{(n-1)\,s_x\,s_y} \quad \text{when} \quad s_x = \sqrt{\frac{\Sigma\,(x-\bar{x})^2}{(n-1)}} \quad \text{and} \quad s_y = \sqrt{\frac{\Sigma\,(y-\bar{y})^2}{(n-1)}}$$

   To begin this equation, you must first calculate the average of all x coordinates (the average of all x coordinates is represented with the letter x with a bar over the top), and the average of all y coordinates (the average of all y coordinates is represented with the letter y with a bar over the top) then use those averages to calculate the standard deviation of x (written as s_x) and the standard deviation of y (written as s_y) for use in the r_{yx} formula. The following chart will help you work through all the steps of this calculation to reach the final r-value.

Test of Correlation Data Analysis Helper	x coordinate calculations		y coordinate calculations
Average of all x coordinates $\bar{x}$ =		Average of all y coordinates $\bar{y}$ =	
Using each x coordinate one at a time, subtract the average of x and square the difference, then add that value to the next value to get: $\Sigma (x-\bar{x})^2$ =		Using each y coordinate one at a time, subtract the average of y and square the difference, then add that value to the next value to get: $\Sigma (y-\bar{y})^2$ =	
Divide the above number by (n-1)		Divide the above number by (n-1)	
Take the square root of the above number. This is the standard deviation of x (written s_x)		Take the square root of the above number. This is the standard deviation of y (or s_y)	
Write out the sum of all x coordinates minus the average of the x coordinates times all y coordinates minus the average of the y coordinates and solve Or $\Sigma (x-\bar{x})(y-\bar{y})$			
Divide the above result by the number of coordinate points minus 1 multiplied by the standard deviation of x and multiplied by the standard deviation of y Or $(n-1)s_xs_y$ The result will be your r-value.			

6. The "r-value" that is calculated using this equation will fall between 1.0 and -1.0, indicating the relationship between the x and y data (i.e., the relationship between the independent and dependent variables). If the r-value is near either 1.0 or -1.0, the relationship is a strong positive correlation or a strong negative correlation. If the r-value is closer to 0.0, this indicates there is little to no relationship between the independent and dependent variables. What does the r-value of your data indicate? Explain your response.

7. Research the anatomy of a root tip. Determine what factors may have contributed errors and how this experiment could be improved to allow a more accurate statement of the results. Write a full conclusion about the mitotic indices of root tips based on your research and statistical analysis.

Root Tip Cell Cycle Data Analysis

Teacher's Version

Below is an example data set with each calculation worked out in long form to help you practice the calculations ahead of teaching this activity. The data on this example calculations sheet is fabricated; your students will have different numbers and their conclusions may be different based on the individual and class data collected. Only the data charts are given here—please see the student's version for instructions that accompany each data table.

Student Worksheet Part 1: Collection of Cell Cycle Data

My Raw Data Chart of Root Tip Cell Cycle Counts:

Phase of Cell Cycle: Field of vision:	Number of Cells in Interphase (Not in Mitosis)	Number of Cells in Prophase of Mitosis	Number of Cells in Metaphase of Mitosis	Number of Cells in Anaphase of Mitosis	Number of Cells in Telophase of Mitosis
1^{st} field of vision above the root cap	74	19	2	4	1
2^{nd} field of vision above the root cap	81	17	1	1	0
3^{rd} field of vision above the root cap	90	9	0	1	0
4^{th} field of vision above the root cap	97	3	0	0	0
Totals for each phase:	342	48	3	6	1

Total number of cells counted in this data set: 400

Class Raw Data Chart of Root Tip Cell Cycle Counts:

Phase of Cell Cycle: Field of vision:	Number of Cells in Interphase (Not in Mitosis)	Number of Cells in Prophase of Mitosis	Number of Cells in Metaphase of Mitosis	Number of Cells in Anaphase of Mitosis	Number of Cells in Telophase of Mitosis
1^{st} field of vision above the root cap	1690	370	210	150	80
2^{nd} field of vision above the root cap	1770	440	100	90	100
3^{rd} field of vision above the root cap	1980	400	50	40	30
4^{th} field of vision above the root cap	2130	310	20	30	10
Totals for each phase:	7570	1520	380	310	220

Total number of cells counted in this data set: 10,000

Student Worksheet Part 2: Question 1

Class Data for the Percentage of Root Cells in Each Phase of Mitosis:

	Interphase	Prophase	Metaphase	Anaphase	Telophase
Total number of cells from the last row of class data set in Part 1	7570	1520	380	310	220
Multiply the total in each square above by the total number of cells you counted and then divide by the total number of cells the class counted to predicted the expected number for each phase.	% of cells expected to be in Interphase = (7570*400) /10,000 = 303	% of cells expected to be in Prophase = (1520*400) /10,000 = 61	% of cells expected to be in Metaphase = (380*400) /10,000 = 15	% of cells expected to be in Anaphase = (310*400) /10,000 = 12	% of cells expected to be in Telophase = (220*400) /10,000 = 9

Student Worksheet Part 2: Question 2

Chi-squared Data Analysis Helper	**Categories = Phases of Mitosis**					
	Interphase	Prophase	Metaphase	Anaphase	Telophase	**Total**
Observed Cell Counts (o)	342	48	3	6	1	400
Expected Cell Counts (e)	303	61	15	12	9	400
Difference Squared $(o-e)^2$	1521	169	144	36	64	
Difference Squared Divided by Expected $(o-e)^2/e$	5.02	2.77	9.60	3.00	7.11	
The chi-squared value is equal to the sum of all differences squared: $x^2 = \Sigma ((o-e)^2/e)$						27.50 is larger than 9.49, the chi-squared critical value, therefore you should reject the H_0

Student Worksheet Part 2: Question 4

Based on your chi-squared value, do you reject the null hypothesis or do you fail to reject the null hypothesis? Explain your response.

"At this time, given this set of data, I reject the null hypothesis because my calculated chi-squared value (27.50) is larger than the chi-squared critical value (9.49) at 4 degrees of freedom and a $p<5\%$. My data is significantly different from the class data."

Student Worksheet Part 3: Question 3

Class Data for Mitotic Index:

	Interphase	Prophase	Metaphase	Anaphase	Telophase	Total number of cells in mitosis	Total number of cells counted	MI (cells in mitosis/total cells counted *100)
1st field of vision distance from root cap:	1690	370	210	150	80	810	2500	32.4%
2nd field of vision distance from root cap:	1770	440	100	90	100	730	2500	29.2%
3rd field of vision distance from root cap:	1980	400	50	40	30	520	2500	20.8%
4th field of vision distance from root cap:	2130	310	20	30	10	370	2500	14.8%

Student Worksheet Part 3: Questions 5-6

Test of Correlation Data Analysis Helper	x coordinate calculations		y coordinate calculations
Average of all x coordinates ($\bar{x}$) =	If I use (1mm+3mm +5mm+7mm)/4 = 4 mm	Average of all y coordinates ($\bar{y}$) =	(32.4+29.2+20.8+14.8)/4 = 24.3%
Using each x coordinate one at a time, subtract the average of x and square the difference, then add that value to the next value to get: $\Sigma (x-\bar{x})^2$ =	Sum of squared differences: $= (1-4)^2 + (3-4)^2 + (5-4)^2 + (7-4)^2$ = 9 + 1+ 1+ 9 = 20	Using each y coordinate one at a time, subtract the average of y and square the difference, then add that value to the next value to get: $\Sigma (y-\bar{y})^2$ =	$= (32.4-24.3)^2 + (29.2-24.3)^2 + (20.8-24.3)^2 + (14.8-24.3)^2$ = 65.61 + 24.01 + 12.25 + 90.25 = 192.12
Divide the above number by (n-1)	= 20/(4-1) = 6.67	Divide the above number by (n-1)	= 192.12/(4-1) = 64.04
Take the square root of the above number. This is the standard deviation of x (or s_x).	s_x = 2.582	Take the square root of the above number. This is the standard deviation of y (or s_y)	s_y = 8.00
Write out the sum of all x coordinates minus the average of the x coordinates times all y coordinates minus the average of the y coordinates and solve Or $\Sigma (x-\bar{x})(y-\bar{y})$	= (1-4)(32.4-24.3) + (3-4)(29.2-24.3) + (5-4)(20.8-24.3) + (7-4)(14.8-24.3) = (-3)(8.1) + (-1)(4.9) + (1)(-3.5) + (3)(-9.5) = (-24.3) + (-4.9) + (-3.5) + (-28.5) = -61.2		
Divide the above result by the number of coordinate points minus 1 multiplied by the standard deviation of x and multiplied by the standard deviation of y, or $(n-1)s_xs_y$ The result will be your r-value.	r-value = (-61.2) / (4-1)(2.582)(8) r-value = (-61.2) / 61.968 r-value = -0.988 (highly correlated x and y with a negative slope)		

Activity Eleven: Writing Mathematical Expressions to Describe and Predict Data (While Teaching Population Dynamics)

Teaching time: 2 class periods of 50 minutes each

Objectives:

a) For students to improve upon the design of a simulation so the data produced are more accurate.
b) For students to describe a biological relationship with multiple variables using a mathematical equation.
c) For students to understand the processes that increase or decrease the number of individuals in a population.
d) For students to understand how population equilibrium changes in a predator-prey scenario.
e) For students to predict the outcome of a process when it is out of balance with other processes.
f) For students to generate a defensible formula that can be used to describe and predict the population of two interacting species.

Materials:

For each pair of students: one "Foxes and Rabbits" game board (which follows this lesson plan) printed in color and, preferably, laminated, a cup of ~100 white beans, and a cup of ~100 black beans.

Procedure:

1. Prior to class, gather the materials above.
2. Once the class is ready to begin this activity, ask the paired students to each send a representative to gather the supplies for the game.
3. Walk through one round of Steps 1-5 from the Foxes and Rabbits game board together as a class to ensure the students are all playing the game in the same manner. Because this is a simulation, the directions act as the procedure and the students carrying out the procedure are the scientists. In order to pool the data, it is essential that all the scientists carry out the procedure in the same manner.
4. Ask the students to play a total of 20 rounds of the game or until both species have a population of 0.
5. Create a data chart on a shared spreadsheet or on a white board to tabulate the data from each pair of students.
6. Ask the students to add their data to the board or to the shared spreadsheet as they conclude their 20 rounds of the game. If the data chart is on the board, students will need to record the data when it is completed.

7. Ask the students to work in pairs to synthesize the data so it is easy to see the trends. What you are asking is for the students to determine the best use of one or more of the central tendencies (mean, median, mode, minimum/maximum, variance, standard deviation, standard error of the mean, etc.) for each round of the game or to choose one or more central tendencies to describe the totals at the end of the game. The students will have choices to make since there is no one perfect way to organize and describe this data set. Some pairs may choose one way to describe the data, others will use different parameters entirely, and others may choose to create a graphic description. Learning to describe data that is not perfectly suited to a particular method is one of the main objectives of this activity, so give the students time and support while they try to do this. They may feel frustrated that they do not know the "right" answer. They may be concerned that if they decide independently they'll make the wrong choice, so inform them that different scientists see data differently and that this is a chance for them to simply describe the data as they see it.
8. Once the paired students have settled on some synthesis of the data, ask the students to each describe the following in their notes, supporting their statements with data:
    a. What is the main trend they see in the data?
    b. What is a secondary trend they see in the data?
    c. Are there any outliers to the main or secondary trend?
9. Ask the students to each share their observations with another student in the room who was not their partner for the game.
10. Discuss the main trend, secondary trend and outliers as a class. As students contribute to the conversation, ask them to continuously use data from the shared spreadsheet to support their observations.
11. Ask the students if the game was a realistic simulation of the interaction of foxes and rabbits. If your students have no knowledge of actual fox or rabbit behavior, ask them to think about it more broadly as a predator and prey interaction. It is very likely several students will see flaws in this simulation, as the rules were purposefully written to have inherent problems that will likely be noticed during game play, even if the students have not studied the topic of predator and prey interactions.
12. Choose a specific flaw in the simulation that the students have identified and ask them to work in pairs to each come up with a new rule that can be added to the game in step 3 to improve the simulation.
13. Ask the paired students to each share their rule by having one person from each pair write theirs on the board. Discuss the rules as a class, deciding together on the best wording for the new rule and erasing all other variations.
14. Ask the students to write three sentences on how this rule will impact the data generated in the game. They may want to devote one sentence to each of the following:
    a. How will the main trend be impacted?
    b. How will the secondary trend be impacted?

    c. How will outliers be impacted?

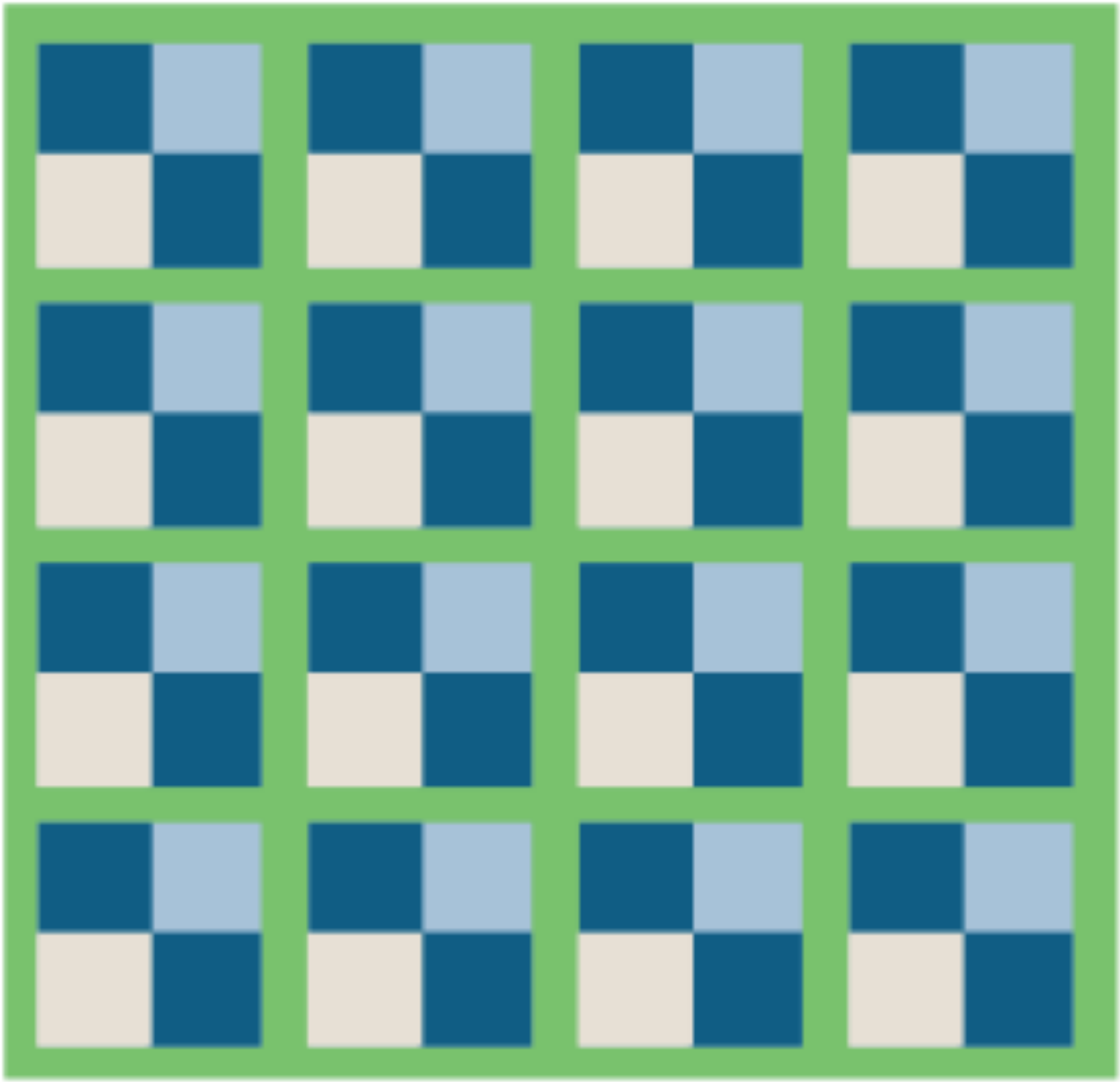
15. Ask the students to play the game again for 20 rounds with the new rule incorporated, to generate a new set of data.
16. Share the data in a new chart or new tab on the existing spreadsheet.
17. Repeat the steps of asking the students to synthesize and describe the new data. Ask the students to discuss, using data-supported answers, whether their predicted data was consistent with the data produced when the new rule was incorporated.
18. Ask the students if the simulation was more accurate with the new rule in place, if the new rule needs to be improved, or if an additional rule is needed.
19. Repeat the steps 10-18 above for generating a new or improved rule and ask the students to predict the data they will see before playing the game again for another 20 rounds.
20. You can repeat this process as many times as needed to create a simulation that the students feel is consistent with their understanding of how predator and prey populations interact. Students can defend their position on whether or not they feel the simulation is accurate by citing support from their textbook or other sources that explains what is understood about predator-prey interactions. If the students do not feel they are knowledgeable enough to decide whether this simulation is accurate, ask them to further research predator-prey relationships until they can defend their assertions.
21. Once the students feel the game play and outcomes can be defended as accurately representing the interactions of predator and prey populations, ask them to work in pairs to build a mathematical equation for the increase and decrease in the population of these two interacting species based on the final rules they created for this game. To help the students build a formula, ask them to first answer the following questions individually, on paper, then with a partner, and then with the entire class:
    a. Consider the rules listed on the Foxes and Rabbits game board and any new rules your class added. What is the mathematical result of each ecological process listed in the rules? *(For example, rule #3a on the Foxes and Rabbits game board concerns the birth of new rabbits, so the mathematical result is an increase in the population by 1 in each case.)*
    b. How many variables are represented by this game? *(For example, in this game, the birth rate for a species is a variable that can either go up or down based on chance positioning and the rules that govern the occurrence of a birth.)*
    c. Which mathematical functions increase the total, and which mathematical functions lead to a decrease in the total? *(For example, the multiplication by numbers greater than 1 result in an increase in the total, while division by numbers greater than 1 result in a decrease.)*
    d. How is probability represented in this simulation?

    e. How will probability be used in the mathematical equation?
    f. These two populations are interdependent. How will you show that in your mathematical equation?
22. Ask the paired students to each share what they have created with another pair of students, defending their ideas.
23. Each pair is likely to write their equation in a different way. They may write the rabbit population as a factor of the fox population or the other way around. Point this out and give the students time to determine the differences and similarities between their ideas and their peers'. Within each group of four students, one student should write down the similarities and differences in what they have created.
24. Allow the students time to continue working in groups of four to improve their mathematical equation. Ultimately they should come to a consensus on an equation they feel describes the population dynamics between the two interacting species.
25. Break the class into groups of 12 or 16, but have the groups of four remain in tact within the larger groups. Have each group of four present their mathematical equation to the other four-person teams in their group. Allow time for clarifying questions so students can determine how the presenters' equation is similar to or different from the one they created in their group.
26. Ask the students to use their equation to predict the ratio of foxes to rabbits at different populations or at different times. For example, you may ask them to create a spreadsheet of different sequential data points or you may ask questions such as:
    a. What would you predict the fox population to be if the rabbit population is 35?
    b. At what point would the fox population be over 100?
    c. What would you predict the rabbit population to be if the fox population fell to 0?
27. Ask the students to compare their predicted values for the rabbit and fox population numbers to those that resulted from the game data during the last 20 rounds of the game (after all the rules had been added or improved).
28. Predicted values for the rabbit and fox populations will not match the game data perfectly. Ask the students why this is so and then ask them to discuss what values would be considered close enough to the actual values to be within an acceptable range. This discussion is about uncertainty and defining what is and is not a "significant difference" in observed versus expected data. Review Activities 1 and 7 as needed.
29. To confirm the skills from this lesson have been acquired and can be applied independently, ask the students to do the following homework:

Application-based Homework:

Ask the students to write down five additional relationships that they feel could be captured in a mathematical equation. You may allow this assignment to include relationships outside the scope of your course (for example, a student may choose to write a mathematics equation for the relationship between happiness and money) or you may limit it to only scientific phenomena that fall in the content areas of your course. Ask the students to define at least two variables that would impact the equation for each relationship. Ask the students to each share their best idea, taking note of the ideas that are most promising. You may decide to come back to some of the mathematical equations proposed by the students throughout the year to further develop student skills describing processes or relationships. If the students are in the IB Diploma Programme, any of the equations could be explored deeply in either an Extended Essay or Internal Assessment.

Foxes and Rabbits



How to play:

1. This game board represents the environment, the light colored beans represent rabbits, and the darker beans represent foxes. Acquire 20 rabbits and 20 foxes to start the game.
2. Mix the rabbits and foxes together thoroughly and place them randomly on any squares on the game board. Each bean should occupy a square by itself if possible, otherwise they can share spaces.
3. After all rabbits and foxes are in place, perform the following:
   a) If a rabbit lands on a dark blue square, it gives birth. (Add a new rabbit to that square.)
   b) If a fox lands on a white square, it dies. (Remove it from the game permanently.)
   c) If a fox lands in the same patch of four squares (outlined by a green border) with a rabbit, then one rabbit is eaten by each fox (remove the rabbit from the game permanently), and each full-bellied fox gives birth to a new fox (add a fox to that square).
4. Count all the rabbits and foxes on the board and record the data at the end of each round.
5. Clear the board of all rabbits and foxes. Repeat steps 2-4 for a total of 20 rounds to generate data.

Appendix E: Alignment with Next Generation Science Standards (NGSS) and Common Core State Standards

	Next Generation Science Standards (NGSS)															
	Scientific and Engineering Practices								Disciplinary Core Ideas	Crosscutting Concepts						
	Asking Questions and Defining Problems	Planning and Carrying Out Investigations	Analyzing and Interpreting Data	Developing and Using Models	Constructing Explanations and Designing Solutions	Engaging in Argument from Evidence	Using Mathematics and Computational Thinking	Obtaining, Evaluating and Communicating Information	LS - Life Science, ESS - Earth and Space Science	Patterns	Cause and Effect: Mechanism and Explanation	Scale, Proportion and Quantity	Systems and System Models: Flows, Cycles and Conservation	Energy and Matter	Structure and Function	Stability and Change
Activity 1	X		X			X	X	X				X				
Activity 2	X	X	X	X	X	X	X	X	LS3.B, LS4.C	X	X	X	X			X
Activity 3	X		X	X	X		X	X		X	X	X				X
Activity 4	X		X	X	X	X		X		X		X	X			
Activity 5	X	X	X		X	X		X		X	X	X	X			
Activity 6	X					X		X		X	X					
Activity 7	X		X	X		X	X	X	LS2.B, ESS3.C	X	X	X				X
Activity 8	X	X	X	X		X	X	X	LS1.A, LS1.B, LS3.A	X	X	X	X		X	X
Activity 9	X		X	X		X	X	X	LS2.B, ESS2.C, ESS3.C	X	X	X	X		X	X
Activity 10	X		X	X	X	X		X		X			X			
Activity 11	X	X	X	X	X	X	X	X	LS2.A, LS2.B, LS2.C, LS2.D, LS4.B	X	v	X	X	X		X
Activity 12	X	X	X	X	X	X	X	X	LS3.B, LS4.A, LS4.B	X	X	X	X			X
Activity 13	X	X	X	X	X	X	X	X	LS1.A, LS3.B, LS4.A, LS4.C, LS4.D	X	X		X		X	X
Activity 14	X	X	X	X	X	X	X	X	LS4.1, LS2.C, LS4.B, LS4.C	X	X	X	X	X		X

	Common Core Standards																		
	English Language Arts Standards					Mathematical Practice								Mathematical Content					
	Reading	Writing	Speaking and Listening	Language	Media and Technology	Make sense of problems and persevere in somving them	Reason abstractly and quantitatively	Construct viable arguments and critique the reasoning of others	Model with mathematics	Use appropriate tools strategically	Attend to precision	Look for and make use of structure	Look for and express regularity in repeated reasoning	Number and quantity	Algebra	Functions	Modeling	Geometry	Statistics and probability
Activity 1		X	X	X		X	X	X	X	X	X	X	X	X	X				X
Activity 2		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X		X
Activity 3		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X		X
Activity 4		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X		X
Activity 5		X	X	X		X	X	X		X	X	X	X	X			X		X
Activity 6		X	X	X		X	X	X		X	X	X	X				X		
Activity 7			X	X		X	X	X	X	X	X	X	X	X	X	X	X		X
Activity 8		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X		X
Activity 9		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X		X
Activity 10		X	X	X		X	X	X	X	X	X	X	X				X		X
Activity 11		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X		X
Activity 12		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
Activity 13		X	X	X	X	X	X	X	X	X	X	X	X	X			X		X
Activity 14		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X		X

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Card Number: ___________________________ Expiration date: _______

Name on card: ______________3-digit security code: ____ Billing zip code: _______

You may either email a picture of this completed form to
Kristen.Dotti@CatalystLearningCurricula.com or
mail the completed form to: Kristen Dotti, 59 Clemmons St., Asheville NC 28801 (Ph: 828-687-0807)