CollegeBoard

AP Biology Investigative Labs:

An Inquiry-Based Approach

Supplement to the First Printing

The College Board
New York, NY

Teacher Manual
Student Manual

ABOUT THE COLLEGE BOARD

The College Board is a mission-driven not-for-profit organization that connects students to college success and opportunity. Founded in 1900, the College Board was created to expand access to higher education. Today, the membership association is made up of over 6,000 of the world's leading educational institutions and is dedicated to promoting excellence and equity in education. Each year, the College Board helps more than seven million students prepare for a successful transition to college through programs and services in college readiness and college success—including the SAT® and the Advanced Placement Program®. The organization also serves the education community through research and advocacy on behalf of students, educators and schools.

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The College Board strongly encourages educators to make equitable access a guiding principle for their AP programs by giving all willing and academically prepared students the opportunity to participate in AP. We encourage the elimination of barriers that restrict access to AP for students from ethnic, racial and socioeconomic groups that have been traditionally underserved. Schools should make every effort to ensure their AP classes reflect the diversity of their student population. The College Board also believes that all students should have access to academically challenging course work before they enroll in AP classes, which can prepare them for AP success. It is only through a commitment to equitable preparation and access that true equity and excellence can be achieved.

AP Biology Investigative Labs: An Inquiry-Based Approach

Supplement to the First Printing

This document provides:

- **Updated URLs**
- **Corrections**
- **Clarifications to lab procedures and equipment needs**
- **Sample data tables for Investigation 7**
- **Updated version of AP Biology Equations and Formulas appendix**

Teacher Manual

Student Manual

Page	Chapter / Investigation	Change
T6	Chapter 1	*In both places it appears in this page, replace LO 4.12 with:* **LO 4.14:** The student is able to apply mathematical routines to quantities that describe interactions among living systems and their environment, which result in the movement of matter and energy.
T45	Chapter 7	*Replace the URL that accompanies "Lemone, P. 2007. GLOBE scientists' blog: Measuring temperature using crickets." with:* http://blog.globe.gov/sciblog/2007/10/05/measuring-temperature-using-crickets/
S6	Chapter 2	*Replace the last two sentences of the first paragraph under Lab Reports/Papers with:* A sample rubric showing what your teacher will be looking for in your lab reports can be found at http://www.biologycorner.com/worksheets/labreport_rubric.html.
S12	Chapter 3	*Replace "Trichome Distribution: Second Distribution" chart with the histogram shown in **Insert A**, later in this document. (The new chart correctly presents the bars without spaces between them).* *Change histogram title to:* Trichome Distribution: Second Generation.
T50	Investigation 1	*In Materials and Equipment list, replace top bullet in right-hand column with:* Fast Plants Seed (F_2 Non-Purple Stem, Yellow-Green Leaf works well and provides additional options explained in The Investigations; it is available as item 158888 from Carolina Biological. Other seed stocks, such as the standard Fast Plants seeds that can be purchased from Carolina Biological or Nasco, work as well).
T54	Investigation 1	*Replace first sentence of third full paragraph on the page with:* As an instructor, you might consider utilizing Carolina Biological item 158888 for this investigation.
T55	Investigation 1	*Replace "Trichome Distribution: First Generation" and "Trichome Distribution: Second Generation" charts with the histograms shown in **Insert B**, later in this document.*
S18	Investigation 1	*In Materials list, replace bottom bullet in left-hand column with:* Fast Plants seed (Carolina Biological item 158888 works well and provides some additional options; it is heterozygous for two Mendelian traits, green/light green leaves and with anthocyanin [purple stems] and without anthocyanin. Other seed stocks, such as the standard Fast Plants seeds that can be purchased from Carolina Biological or Nasco, work as well.)

Page	Chapter / Investigation	Change
S30	Investigation 2	*Insert after fifth sentence in first paragraph:* Each part of the life cycle can be represented by a spreadsheet operation. 1. Set allele frequencies (assign a value to a cell). 2. Use the random function (RAND) to generate a random number which will be compared to the allele frequency from Step 1. 3. Compare the random number to allele frequency and assign the appropriate allele. 4. Repeat Steps 1–3 for the second allele. 5. Use the CONCATENATE function to combine the two alleles to form a zygote. 6. Copy this procedure (Steps 2–5) for multiple offspring. Let's get started.
T72	Investigation 3	*In the last bulleted learning objective on this page, change the science practice from* SP 5.6 *to* SP 6.5.
S45	Investigation 3	*Replace URL in Step 2 with the following AP Central location:* http://apcentral.collegeboard.com/apc/members/courses/teachers_corner/218954.html
T81	Investigation 4	*Replace first sentence of second paragraph with:* The cellular environment is aqueous, meaning that the solutes (e.g., salts, organic molecules) dissolve in water, which is the solvent.
T88	Investigation 4	*Insert the following note under the shaded materials box:* Note: 5% ovalbumin = 5 g/100 mL = 50 g/liter. The MW of ovalbumin is 45,000 g/mole. The molarity of a 5% solution = mole/45,000 g × 50 g/liter = 0.0011 M. *Change the following amounts in the Preparation list:* *1. Change 342 g of sucrose to* 342.3 g *of sucrose* *2. Change* 58.44 g *of NaCl to* 58.4 g *of NaCl* *3. Change* 180 g *of glucose to* 180.2 g *of glucose*
T90	Investigation 4	*Under Preparation, change* 648.6 g of sucrose *to:* 684.6 g of sucrose
T92	Investigation 4	*Replace the URL that accompanies "The Nobel Prize in Chemistry 2003 was awarded to Peter Agre and Roderick MacKinnon for their work on aquaporins. The Nobel Prize website provides information about these protein channels and their roles in osmosis." with:* http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2003
S51	Investigation 4	*Replace first sentence of second paragraph with:* The cellular environment is aqueous, meaning that the solutes (e.g., salts, organic molecules) dissolve in water, which is the solvent.
T127	Investigation 7	*Under Part 2: Effects of Environment on Mitosis, add the following bullet under "Dissection scissors":* • Dissection probes or needles

Page	Chapter / Investigation	Change
T130	Investigation 7	*Replace final paragraph under Part I with:* Students can use sockosomes, Pop-It Beads, clay, or pipe cleaners to review chromosome duplication and movement.
T133	Investigation 7	*In Step 1 under "Preparing Chromosome Squashes," change* 12 *M HCl to* 1 *M HCl.* *Change Step 7 to:* 7. Gently tease the root tip apart with dissecting probes or needles. Place the cover slip over the root tip and cover the cover slip with a scientific cleaning wipe.
T134	Investigation 7	*Replace entire existing page with new text and tables as shown in* ***Insert C****, later in this document.*
T142	Investigation 7	*Replace the final entry under "Other Resources" with:* http://www.biology.arizona.edu/human_bio/activities/karyotyping/karyotyping.html This online activity from The Biology Project covers karyotype analyses in normal cells and in cells carrying a genetic defect.
S87	Investigation 7	*Add* Pop-It Beads *to the second sentence under "Part I: Modeling Mitosis."*
S88	Investigation 7	*In Step 1 under "Preparing Chromosome Squashes," change* 12 *M HCl to* 1 *M HCl.* *Change Step 7 to:* **7.** Gently tease the root tip apart with dissecting probes or needles. Place the cover slip over the root tip and cover the cover slip with a scientific cleaning wipe.
S89	Investigation 7	*Replace all text and tables above "Postlab Review" with new text and tables as shown in* ***Insert D****, later in this document.*
S95	Investigation 7	*Change Step 6 to:* **6.** Enter the data in Table 3 and make the calculations. One map unit equals one percent recombination. The percent of asci showing recombination divided by 2 equals the map units separating the spore-color gene from the centromere. The percent of asci showing recombination is divided by 2 because only half of the spores in each ascus are the result of a crossing-over event.
T159	Investigation 8	*Replace the URL in the second paragraph under "Procedural Resources" with:* http://www.carolina.com
T173	Investigation 9	*Replace the URL that accompanies the third entry under "Resources for Extensions of Investigation" with:* https://www.bio-rad.com/cmc_upload/Products/-41683/Get_A_Clue_DESTINY.pdf
S119	Investigation 9	*In Step 1, reverse the colors so that "positive (+) electrode to positive (+) electrode" is described as "(red to red)" and "negative (-) electrode to negative (-) electrode" is described as "(black to black)."*
APPENDIX A APPENDIX A		*In both the Teacher Manual and Student Manual, replace existing Appendix A: AP Biology Equations and Formulas with updated version (see* ***Insert E****, later in this document).*

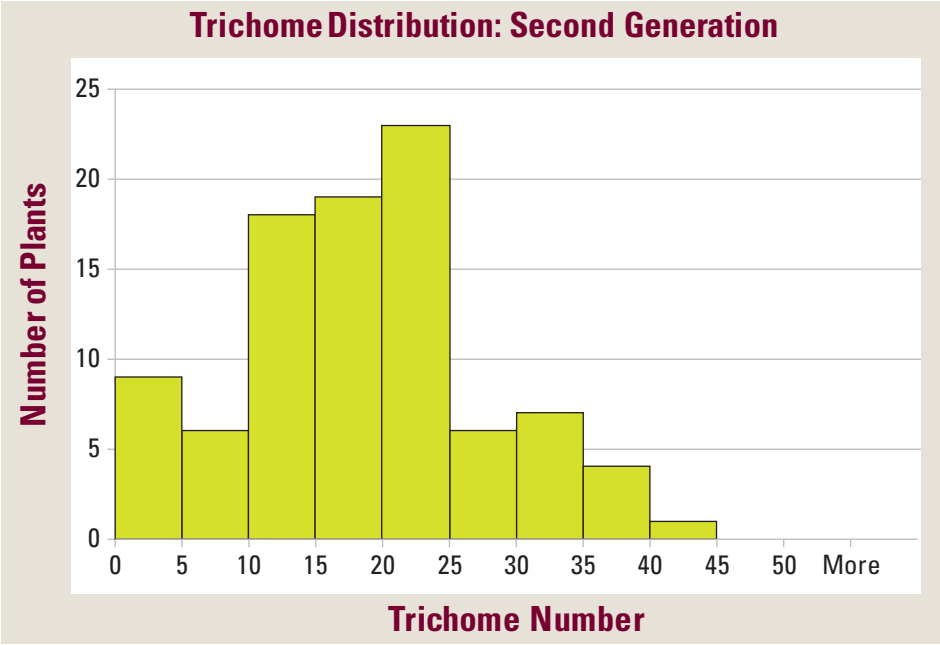

Figure 2. Trichome Distribution: Second Generation

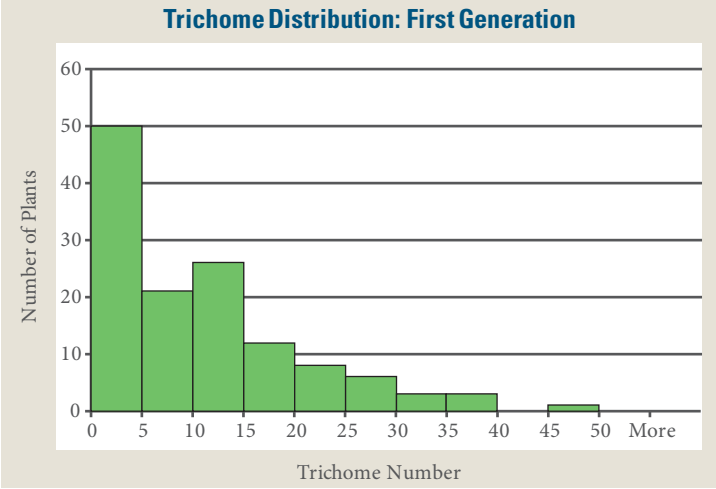

Figure 1. Trichome Distribution: First Generation

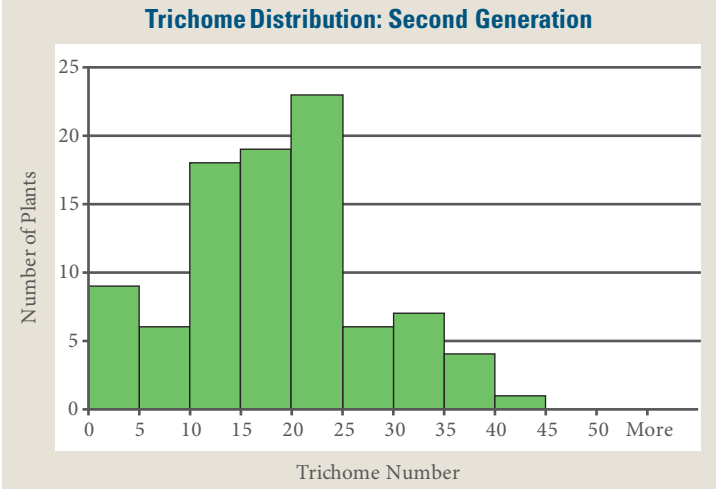

Figure 2. Trichome Distribution: Second Generation

Table 2. Table of Observed Values (o)

	Interphase	Mitosis	Total
Control	A	B	A + B
Treated	C	D	C + D
Total	A + C	B + D	A + B + C + D = N

1. Collect the class data and enter the values into Table 1; these are the observed values for the four groups.
2. Use the data from Table 1 to calculate the totals using the formulas found in Table 2. (For example, A equals the number of interphase cells in the control group.)
3. Use the totals from Table 2 to calculate the expected values (e) using the formulas from Table 3.
4. Enter the observed values (o) from Table 2 and expected values (e) from Table 3 for each group into Table 4. Calculate the chi-square (χ^2) value for the data by adding together the numbers in the right column.
5. Compare this value to the critical value in Table 5.

Table 3. Table of Expected Values (e)

	Interphase	Mitosis
Control	$\frac{(A + B)(A + C)}{N}$	$\frac{(A + B)(B + D)}{N}$
Treated	$\frac{(C + D)(A + C)}{N}$	$\frac{(C + D)(B + D)}{N}$

Table 4. Calculation of Chi-Square Value

Group	Observed (o)	Expected (e)	(o - e)	$(o - e)^2$	$(o - e)^2/e$
Control Interphase					
Control Mitosis					
Treated Interphase					
Treated Mitosis					

Total of $(o - e)^2/e$ = chi-square (χ^2) =

Table 5. Critical Values of the Chi-Square Distribution

Probability	Degrees of Freedom (DF)				
	1	2	3	4	5
0.05	3.84	5.99	7.82	9.49	11.1
0.01	6.64	9.21	11.3	13.2	15.1
0.001	10.8	13.8	16.3	18.5	20.5

1. The degrees of freedom (df) equals the number of treatment groups minus one multiplied by the number of phase groups minus one. In this case, there are two treatment groups (control, treated) and two phase groups (interphase, mitosis); therefore df = (2 - 1) (2 - 1) = 1.
2. The ρ value is 0.05, and the critical value is 3.84. If the calculated chi-square value is greater than or equal to this critical value, then the null hypothesis is rejected. If the calculated chi-square value is less than this critical value, the null hypothesis is not rejected.

SAMPLE DATA

Sample Table 2: Table of Observed Values (o)

	Interphase	Mitosis	Total
Control	148	25	173
Treated	161	88	249
Total	309	113	422

Sample Table 3: Table of Expected Values (e)

	Interphase	Mitosis
Control	127	46
Treated	179	67

Sample Table 4: Calculation of Chi-Square Value

Group	Observed (o)	Expected (e)	(o - e)	$(o - e)^2$	$(o - e)^2/e$
Control Interphase	148	127	21	441	3.47
Control Mitosis	25	46	-21	441	9.59
Treated Interphase	161	182	-21	441	2.42
Treated Mitosis	88	67	21	441	6.58

Total of $(o - e)^2/e$ = chi-square (χ^2) = 22.06

Since the calculated χ^2 is greater than the table value, the null hypothesis (treatment has no effect) is rejected.

Table 2. Table of Observed Values (o)

	Interphase	Mitosis	Total
Control	A	B	A + B
Treated	C	D	C + D
Total	A + C	B + D	A + B + C + D = N

1. Collect the class data and enter the values into Table 1; these are the observed values for the four groups.
2. Use the data from Table 1 to calculate the totals using the formulas found in Table 2. (For example, A equals the number of interphase cells in the control group.)
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Table 3. Table of Expected Values (e)

	Interphase	Mitosis
Control	$\frac{(A + B)(A + C)}{N}$	$\frac{(A + B)(B + D)}{N}$
Treated	$\frac{(C + D)(A + C)}{N}$	$\frac{(C + D)(B + D)}{N}$

Table 4. Calculation of Chi-Square Value

Group	Observed (o)	Expected (e)	(o - e)	$(o - e)^2$	$(o - e)^2/e$
Control Interphase					
Control Mitosis					
Treated Interphase					
Treated Mitosis					

Total of $(o - e)^2/e$ = chi-square (χ^2) =

Table 5. Critical Values of the Chi-Square Distribution

Probability	Degrees of Freedom (DF)				
	1	2	3	4	5
0.05	3.84	5.99	7.82	9.49	11.1
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2. The ρ value is 0.05, and the critical value is 3.84. If the calculated chi-square value is greater than or equal to this critical value, then the null hypothesis is rejected. If the calculated chi-square value is less than this critical value, the null hypothesis is not rejected.

AP BIOLOGY EQUATIONS AND FORMULAS

Statistical Analysis and Probability

Mean

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Standard Deviation*

$$S = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

Standard Error of the Mean*

$$SE_{\bar{x}} = \frac{s}{\sqrt{n}}$$

Chi-Square

$$\chi^2 = \sum \frac{(o-e)^2}{e}$$

Chi-Square Table

p value	Degrees of Freedom							
	1	2	3	4	5	6	7	8
0.05	3.84	5.99	7.82	9.49	11.07	12.59	14.07	15.51
0.01	6.64	9.21	11.34	13.28	15.09	16.81	18.48	20.09

$\bar{x}$ = sample mean

n = size of the sample

s = sample standard deviation (i.e., the sample-based estimate of the standard deviation of the population)

o = observed results

e = expected results

Degrees of freedom are equal to the number of distinct possible outcomes minus one.

Laws of Probability

If A and B are mutually exclusive, then:

$$P(\text{A or B}) = P(\text{A}) + P(\text{B})$$

If A and B are independent, then:

$$P(\text{A and B}) = P(\text{A}) \times P(\text{B})$$

Hardy-Weinberg Equations

$p^2 + 2pq + q^2 = 1$

$p + q = 1$

p = frequency of the dominant allele in a population

q = frequency of the recessive allele in a population

Metric Prefixes

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Mode = value that occurs most frequently in a data set

Median = middle value that separates the greater and lesser halves of a data set

Mean = sum of all data points divided by number of data points

Range = value obtained by subtracting the smallest observation (sample minimum) from the greatest (sample maximum)

** For the purposes of the AP Exam, students will not be required to perform calculations using this equation; however, they must understand the underlying concepts and applications.*

Rate and Growth

Rate

$\frac{dY}{dt}$

Population Growth

$\frac{dN}{dt} = B - D$

Exponential Growth

$\frac{dN}{dt} = r_{max} N$

Logistic Growth

$\frac{dN}{dt} = r_{max} N \left(\frac{K - N}{K} \right)$

Temperature Coefficient Q_{10} †

$Q_{10} = \left(\frac{k_2}{k_1} \right)^{\frac{10}{T_2 - T_1}}$

Primary Productivity Calculation

$\frac{\text{mg } O_2}{\text{L}} \times \frac{0.698 \text{ mL}}{\text{mg}} = \frac{\text{mL } O_2}{\text{L}}$

$\frac{\text{mL } O_2}{\text{L}} \times \frac{0.536 \text{ mg C fixed}}{\text{mL } O_2} = \frac{\text{mg C fixed}}{\text{L}}$

(at standard temperature and pressure)

dY = amount of change

dt = change in time

B = birth rate

D = death rate

N = population size

K = carrying capacity

r_{max} = maximum per capita growth rate of population

T_2 = higher temperature

T_1 = lower temperature

k_2 = reaction rate at T_2

k_1 = reaction rate at T_1

Q_{10} = the factor by which the reaction rate increases when the temperature is raised by ten degrees

Water Potential (Ψ)

$\Psi = \Psi_P + \Psi_S$

Ψ_P = pressure potential

Ψ_S = solute potential

The water potential will be equal to the solute potential of a solution in an open container because the pressure potential of the solution in an open container is zero.

The Solute Potential of a Solution

$\Psi_S = -iCRT$

i = ionization constant (this is 1.0 for sucrose because sucrose does not ionize in water)

C = molar concentration

R = pressure constant (R = 0.0831 liter bars/mole K)

T = temperature in Kelvin (°C + 273)

Surface Area and Volume

Volume of a Sphere

$V = \frac{4}{3} \pi r^3$

Volume of a Rectangular Solid

$V = lwh$

Volume of a Right Cylinder

$V = \pi r^2 h$

Surface Area of a Sphere

$A = 4\pi r^2$

Surface Area of a Cube

$A = 6s^2$

Surface Area of a Rectangular Solid

$A = \sum$ surface area of each side

r = radius

l = length

h = height

w = width

s = length of one side of a cube

A = surface area

V = volume

Σ = sum of all

Dilution (used to create a dilute solution from a concentrated stock solution)

$C_i V_i = C_f V_f$

i = initial (starting)
f = final (desired)

C = concentration of solute
V = volume of solution

Gibbs Free Energy

$\Delta G = \Delta H - T\Delta S$

ΔG = change in Gibbs free energy

ΔS = change in entropy

ΔH = change in enthalpy

T = absolute temperature (in Kelvin)

pH* = $-\log_{10} [H^+]$

** For the purposes of the AP Exam, students will not be required to perform calculations using this equation; however, they must understand the underlying concepts and applications.*

† For use with labs only (optional).