Worksheet M01: Data, Uncertainty, and Testing a Model

Name _____ Date _____ Period _____

Use this with the AP Biology Equations and Formulas sheet. Show every step: the numbers you start with, the relationship you chose, the substitution with units, the answer, and what it means biologically. This sheet is practice, not a graded test.

The routine for every calculation

1. Known values 2. Target quantity 3. Relationship (from the formula sheet) 4. Substitute with units 5. Answer 6. Biological meaning

Mean: $\bar{x} = \Sigma x \div n$ **Sample standard deviation:** $s = \sqrt{[\ \Sigma(x - \bar{x})^2 \div (n - 1)\ ]}$

Standard error of the mean: $SE_{\bar{x}} = s \div \sqrt{n}$ **Error bars of ±2 SE:** $\bar{x} - 2SE$ to $\bar{x} + 2SE$

Chi-square: $\chi^2 = \Sigma\ (o - e)^2 \div e$ **Degrees of freedom:** df = number of categories − 1

Reading error bars: First check what the bars show (SD, SE, or a confidence interval). With suitable sampling assumptions and a sufficiently large sample, ±2 SE bars approximate a 95% confidence interval. If ±2 SE bars do not overlap, the difference is likely significant. Overlap alone cannot establish whether a difference is significant; use the specified statistical test. It does not prove no difference.

Part A — Describing data and its uncertainty

A1. Worked example

Four bean seedlings grown in the same conditions reached heights of 10, 12, 14, and 12 cm. Find the mean, the standard deviation, the standard error, and the ±2 SE interval.

x (cm)	$x - \bar{x}$ (cm)	$(x - \bar{x})^2$ (cm²)
10	−2	4
12	0	0
14	+2	4
12	0	0
$\Sigma x = 48$		$\Sigma(x - \bar{x})^2 = 8$

Known values: n = 4; heights 10, 12, 14, 12 cm.

Mean: $\bar{x} = 48$ cm $\div 4 = 12$ cm.

Standard deviation: $s = \sqrt{(8\ cm^2 \div (4 - 1))} = \sqrt{2.67\ cm^2} = 1.63$ cm. Divide by n − 1, not n, for a sample.

Standard error: SE = 1.63 cm $\div \sqrt{4} = 1.63 \div 2 = 0.82$ cm.

±2 SE interval: 12 − 1.63 = 10.4 cm to 12 + 1.63 = 13.6 cm.

Biological meaning: A typical seedling was about 12 cm tall, and individual plants varied by about 1.6 cm. The calculated ±2 SE interval is 10.4–13.6 cm. With only four seedlings, do not assume this is a 95% confidence interval.

A2. Partly completed example — finish the missing steps

Five crickets chirped 8, 9, 11, 12, and 15 times in 15 seconds at the same temperature.

x (chirps)	$x - \bar{x}$	$(x - \bar{x})^2$
8	−3	9
9		
11	0	0
12		
15		
$\Sigma x = 55$		

Mean: $\bar{x} = 55 \div 5 = 11$ chirps

Standard deviation: $s = \sqrt{(_____ \div (___ - 1))} = _____$ chirps

Standard error: SE = _____ ÷ √5 = _____ chirps

±2 SE interval: from _____ to _____ chirps

A3. Your turn — show the routine for each problem

1. Five leaves from one tree measured 6.2, 5.8, 6.6, 7.0, and 6.4 cm. Calculate the mean and the range, with units.

_____

_____

2. Three replicate enzyme trials produced 20, 22, and 24 mL of oxygen. Calculate the sample standard deviation. Show the deviation table.

_____

_____

_____

_____

3. A sample of 16 fish has a mean mass of 30 g and a standard deviation of 4.0 g. Calculate the standard error and the ±2 SE interval.

_____

_____

_____

4. Plants grown with fertilizer had a mean mass of 36 g (SE = 1.5 g). Control plants had a mean mass of 30 g (SE = 1.0 g). Calculate both ±2 SE intervals. Do they overlap? What can you conclude?

_____

_____

_____

_____

5. Group A has a mean of 14.0 mm (SE = 0.8 mm); group B has a mean of 15.0 mm (SE = 0.9 mm). Calculate both ±2 SE intervals. Write a conclusion that does not overstate the evidence.

6. Two studies measured the same trait and both found s = 6.0 cm. Study 1 used n = 4; study 2 used n = 36. Calculate each SE and explain which mean is the more precise estimate.

A4. Error analysis

7. A student was given s = 5.0 g and n = 25 and wrote "SE = 5.0 ÷ 25 = 0.2 g." Then the student wrote "Our ±2 SE bars overlap with the control bars, so the treatment had no effect." Identify and correct both mistakes.

A5. Biological interpretation

8. Use your answers to problem 4. Write one claim, cite the evidence (the two intervals), and give one reason the result might differ if the experiment were repeated.

Part B — Testing a model with chi-square (introduction)

Chi-square compares the counts you observed (o) with the counts a model, the null hypothesis, predicts (e). A small χ^2 means the data fit the model; a large χ^2 means the difference is unlikely to be due to chance alone.

df	1	2	3	4	5
Critical value (p = 0.05)	3.84	5.99	7.81	9.49	11.07

Decision rule: if χ^2 is greater than the critical value, reject the null hypothesis. If χ^2 is less than or equal to it, fail to reject the null hypothesis ("fail to reject" is not the same as "prove").

B1. Worked example

100 pill bugs were placed in a choice chamber with a dark side and a light side. After 10 minutes, 62 were on the dark side and 38 on the light side. Null hypothesis: pill bugs show no preference, so 50 and 50 are expected.

Side	Observed (o)	Expected (e)	o − e	$(o - e)^2$	$(o - e)^2 \div e$
Dark	62	50	+12	144	2.88
Light	38	50	−12	144	2.88
Total	100	100			$\chi^2 = 5.76$

df = 2 categories − 1 = 1. Critical value = 3.84. **5.76 > 3.84, so reject the null hypothesis.**

Biological meaning: The pill bugs' distribution is unlikely to be due to chance alone; the data support a preference for the dark side.

B2. Partly completed example

120 seeds were planted, 60 in each of two soil types. Null hypothesis: soil type does not affect germination, so the 60 germinated seeds should split 30 and 30. Observed: 36 in soil X and 24 in soil Y.

Soil	o	e	o − e	$(o - e)^2$	$(o - e)^2 \div e$
X	36	30	+6	36	
Y	24				
Total	60	60			

df = _____ Critical value = _____ Decision: _____

B3. Your turn

9. 90 ants were offered three baits. Null hypothesis: no preference (30 at each). Observed: sugar 42, protein 25, oil 23. Build the table, calculate χ^2, state df and the critical value, and decide.

10. 120 pill bugs were placed in a four-chamber choice arena. Null hypothesis: no preference (30 per chamber). Observed: 35, 28, 31, 26. Calculate χ^2 and decide.

B4. Error analysis

11. For problem 9, a student calculated $(42 - 30) \div 30 + (25 - 30) \div 30 + (23 - 30) \div 30 = 0$ and concluded the ants have no preference. What went wrong?

B5. Biological interpretation

12. In problem 10 you failed to reject the null hypothesis. A classmate says, "So we proved pill bugs have no preference." Rewrite the conclusion so it matches the evidence, and suggest one change to the experiment that would give a stronger test.