

Supplemental Material

CBE—Life Sciences Education

Chrispeels et al.

Supplementary Table 1. 2102 content assessment pre-/post-test questions and scoring sheet used for grading.

Question	Answer components	Points
1. What parts of a plant participate in reproduction? Please describe the role of at least four of these parts in reproduction.	Identifies a flower as a reproductive structure	2
	Lists four reproductive flower parts (1 point each)	4
	Correctly describes role for each part listed (1 point each)	4
2. Curly hair is dominant over straight hair. Use a Punnett square (or Punnett squares!) to demonstrate the probability of curly-haired children from the marriage of a curly-haired woman to a man with straight hair.	CC x cc Punnett square listed	1
	Cc x cc Punnett square listed	1
	Both filled in correctly (one parent allele for each row and column, correct letter combos for children, dominant allele listed first in heterozygote)	5
	Correct percentage/ratio described	2
	Relates results to genotype of curly haired woman	1
3. What is the difference between a phenotype and genotype? Between heterozygous and homozygous?	Correct definition of phenotype	2.5
	Correct definition of genotype	2.5
	Homozygous definition	2
	Both dominant and recessive possibilities mentioned	1
	Heterozygous definition	2
4. The human genome is huge (3.4 billion base pairs!). If you wanted to get a gene out of the genome, and make lots of copies of it to study, how could you do that?	Mentions using the PCR technique	2
	Writes full name: polymerase chain reaction	1
	States DNA is amplified; many copies produced	1
	Describes process of PCR: Makes copies of DNA using <u>enzymes</u> and <u>primers</u> (mimics DNA replication)	3
	Cycles of heating and cooling are essential for process	3
5. What is gel electrophoresis used for? In one or two sentences, how does it work?	Describes process of gel electrophoresis by saying:	
	DNA loaded in gel is separated by size using current	4
	Smaller fragments travel faster than larger fragments	2
	Smaller bands are found at the bottom of the gel, larger bands towards top	2
	DNA is negatively charged, and moves towards positive end of gel/electrode	2

Supplementary Table 2. Z, W, and *p*-values for statistical tests used in comparisons of pre- and post-test scores for 2012 and 2013, and final exam scores for 2012. *p*-values reflect application of false discovery rate control to all statistical tests. Significance determined at *p* < 0.05. MS = MS undergraduates, HS = HS undergraduates. Pre = pre-test, post= post-test.

2012 pre- and post-tests				
Test used	Exact Wilcox signed rank		Mann Whitney U	
Question	MS undergrads, pre vs. post	HS undergrads, pre vs. post	MS vs. HS, pre- test	MS vs. HS, post- test
1	Z = 3.61 p = 7.1 e-05	Z = 5.325 p = 5.8 e-10	W = 424 p = 0.27	W = 436 p = 0.27
2	Z = 3.45 p = 0.0004	Z = 4.20 p = 1.6 e-05	W = 429 p = 0.27	W = 295 p = 0.27
3	Z = 3.71 p = 4.8 e-05	Z = 4.49 p = 3.0 e-06	W = 469 p = 0.095	W = 483 p = 0.065
4	Z = 1.73 p = 0.27	Z = 5.38 p = 5.8 e-10	W = 323 p = 0.077	W = 685 p = 1.2 e-07
5	Z = 1.996 p = 0.18	Z = 5.32 p = 7.7 e-10	W = 369 p = 0.824	W = 643 p = 3.9 e-06
2013 pre- and post-tests				
Test used	Exact Wilcox signed rank		Mann Whitney U	
Question	All students, pre vs. post		MS vs. HS, post test	
1A	Z = 4.43; p = 9.9 e-06		W = 370; p = 0.55	
1B	Z = 1.64; p = 0.15		W = 333; p = 0.95	
2A	Z = 5.395; p = 2.1 e-08		W = 391; p = 0.35	
2B	Z = 4.89; p = 4.6 e-07		W = 243; p = 0.11	
3A	Z = 5.46; p = 9.7 e-09		W = 283; p = 0.35	
3B	Z = 5.03; p = 1.3 e-07		W = 298; p = 0.40	
4A	Z = 5.79; p = 7.0 e-08		W = 474; p = 0.01	
4B	Z = 4.54; p = 2.9 e-06		W = 455; p = 0.02	
5A	Z = 5.95; p = 2.6 e-10		W = 460; p = 0.03	
5B	Z = 5.43; p = 8.9 e-09		W = 441; p = 0.07	
6A	Z = 5.57; p = 3.5 e-09		W = 494; p = 0.004	
6B	Z = 5.51; p = 5.6 e-09		W = 564; p = 2.9 e-05	
Test used	Exact Wilcox signed rank		Mann Whitney U	
Question	MS undergrads, pre vs. post	HS undergrads, pre vs. post	MS vs. HS, pre- test	MS vs. HS, post- test
1	Z = 3.73 p = 0.0002	Z = 2.04 p = 0.06	W = 416 p = 0.18	W = 360 p = 0.71
2	Z = 3.76 p = 1.2 e-06	Z = 4.41 p = 1.7 e-06	W = 332 p = 0.95	W = 295 p = 0.49
3	Z = 3.85 p = 4.4 e-05	Z = 4.31 p = 3.0 e-06	W = 242 p = 0.11	W = 258 p = 0.18
4	Z = 3.41 p = 0.001	Z = 4.64 p = 7.9 e-08	W = 360 p = 0.24	W = 520 p = 0.001

5	Z = 3.8 p = 6.7 e-05	Z = 4.64 p = 4.5 e-08	W = 416 p = 0.18	W = 485 p = 0.01
6	Z = 4.16 p = 1.5 e-07	Z = 4.61 p = 1.3 e-07	W = 339 p = 0.95	W = 574 p = 2.6 e-05
2012 Final Exam				
Test used	Mann Whitney U			
Question	MS vs. HS			
1	W = 477; p = 0.66			
2	W = 560; p = 0.09			
3	W = 434; p = 0.57			
4	W = 446; p = 0.68			
5	W = 679; p = 0.001			
6	W = 576; p = 0.09			
Test used	Exact Wilcox signed rank		Mann Whitney U	
Question set	MS	HS	MS vs. HS	
Common curriculum questions	vs. other exam questions Z = 3.5 p = 0.001	vs. other exam questions Z = 4.8 p = 2.0 e-06	W = 351; p = 0.13	
HS-specific questions	vs. other exam questions Z = 3.7 p = 0.0004	vs. other exam questions Z = -2.2 p = 0.07	W = 697; p = 0.001	
Other exam questions	N/A	N/A	W = 614; p = 0.07	
Test Used	Exact Wilcox signed rank		Mann Whitney U	
Question set	MS	HS	MS vs. HS	
Lecture & lab questions	vs. Lecture only questions Z = -0.71 p = 0.59	vs. Lecture only questions Z = 0.36 p = 0.73	W = 591; p = 0.09	
Lecture only questions	N/A	N/A	W = 603; p = 0.09	

Supplementary Table 3. 2013 questions and grading rubric for content assessment pre- and post-tests.

Points	0	1	2	3	4
<p>1A. Below are listed the events in fertilization and fruit production. List the numbers of the events in the correct order.</p>	No response or completely incorrect sequence of steps	Only 1-2 steps are in the correct sequence	3-5 steps are in the correct sequence, including pairs that are in the right order but not in the right position	6-7 steps are in the correct sequence OR #4 is out of order but rest of sequence is correct #8 and #1 must be near the end even if all other steps are in correct order to get 3 points.	The sequence of steps is accurately listed: 3-6-2-5-7-4-8-1
<p>1B. If a plant cannot produce pollen, how would that affect its ability to produce fruit? Describe and explain.</p>	No response or completely incorrect information	Response only contains 1 of the 7 possible parts of the answer	Response contains 2 of the 7 possible parts of the answer	Response contains 3 of the 7 possible parts of the answer	Response explains at least 4 of the following: <ol style="list-style-type: none"> 1. This plant could not produce fruit 2. Pollen is the male part of the plant 3. Pollen is required for fertilization OR pollen fertilizes the egg 4. This plant cannot pollinate itself 5. This plant could be pollinated by another plant 6. This plant cannot fertilize other plants 7. Fertilization is required for fruit production.
<p>2A. Define the terms “genotype” and “phenotype”.</p>	No response or completely incorrect definition	Response defines phenotype or genotype (but not both) without providing context by referring to traits or the organism	Response correctly defines genotype OR phenotype, but not both. OR defines genotype and phenotype without referring to traits or the organism—both without context	Response correctly defines genotype as the combination of <i>genes</i> or <i>genetic makeup</i> in an organism or individual or for a trait AND phenotype as the physical appearance of the organism or	Response correctly defines genotype as the combination of <i>alleles</i> for a gene, trait, or organism, AND phenotype as the physical appearance of the organism or expression of the alleles.

				individual or expression of the trait or gene. OR has a correct definition for either phenotype or genotype AND an almost complete definition for the other	
2B. In 2 or 3 sentences, explain why two different genotypes (representing the same gene) might give the same phenotype.	No response or completely incorrect information	Mentions that dominant traits/genes/alleles always expressed or that there can be dominant and recessive traits OR mentions that there can be heterozygous and homozygous genotypes BUT NOT BOTH	Response mentions BOTH that heterozygous and homozygous genotypes exist AND mentions that a dominant allele/gene/trait will always be expressed BUT does not explain the connection	Response explains that dominant <i>genes</i> will always be expressed and explains that heterozygous and homozygous dominant genotypes <i>will give the same phenotype</i> . Can use an example in place of a written-out explanation.	Response explains clearly that there are recessive and dominant <i>alleles</i> , and that dominant alleles will always be expressed in the phenotype. Makes the connection to the concept that heterozygous and homozygous dominant genotypes will give the same phenotype. Can use an example.
3A. Define the terms “homozygous” and “heterozygous”.	No response or completely incorrect definition	Response includes some correct terminology, or an example, but does not correctly define either homozygous or heterozygous.	Response correctly defines homozygous OR heterozygous, but not both OR defines the terms by saying “2 of the same alleles” without referring to genotype or trait (No context).	Response defines homozygous as a trait or genotype with 2 of the same genes and heterozygous as a trait or genotype with 2 different genes (Rather than alleles). Answer includes context.	Response correctly defines homozygous as a genotype or trait consisting of 2 identical <i>alleles</i> and heterozygous as a genotype or trait consisting of 2 different alleles. Answer includes context.
3B. Brown eye color is dominant over blue eye color. Imagine that a heterozygous brown-eyed woman and a blue-eyed man have children. Set up a Punnett square to demonstrate the fraction of brown-eyed	No response or completely incorrect Punnett square	Response includes a Punnett square with incorrect parental alleles OR incorrect offspring genotypes.	Response includes a correct Punnett square but no or incorrect fraction of offspring phenotypes.	Response includes a correct Punnett square AND a correct NUMBER, but not a correct fraction, e.g. 2 brown, 2 blue	Response includes a correct Punnett square, AND a correct fraction of offspring phenotypes (expressed as fraction or percentage)

children from this couple. Use the letters B and/or b to designate alleles.					
4A. List 3 essential components that are required to carry out a polymerase chain reaction (PCR) experiment.	No response or completely incorrect items listed	1 correct items listed (component or step)	2 correct items listed (components or steps)	3 items listed, 1 or 2 are steps rather than components (see list below) OR 3 steps are listed	Response includes 3 correct components: DNA, gene-specific primers, DNA polymerase; no steps are substituted for components OR 3 steps that clearly explain process (see below)
4B. The Polymerase Chain Reaction is dependent on multiple cycles of polymerization. Explain why multiple cycles are needed for the technique to work as it should.	No response or completely incorrect information	Response mentions something correct about the PCR technique.	Response mentions that a large amount or multiple copies of DNA is produced	Response explains that PCR increases the amount of DNA with each cycle OR says that DNA increases exponentially but does not say <i>with each cycle</i>	Response explains that PCR <i>exponentially</i> increases the amount of DNA with each cycle.
5A. What is the objective of the technique of DNA gel electrophoresis? In other words, what does the technique do?	No response or completely incorrect information	Response includes something correct about the technique. Should give something more than just mentioning DNA, which they can get from the question itself.	Response explains that gel electrophoresis is used to view mutations, doesn't include any other correct information (application of method)	Response explains that gel electrophoresis separates fragments of DNA according to size	Response explains that gel electrophoresis separates fragments of DNA according to size. Also mentions that charge is used in the process.
5B. You are running a DNA electrophoresis gel and you discover that you accidentally reversed the positive and negative electrodes. What will	No response or completely incorrect response	Response mentions that DNA is negatively charged, OR that DNA is attracted to the positive electrode, but does not explain how DNA will move.	Response explains that DNA will not move in gel or will move out of top of gel without mentioning that DNA is negatively charged OR saying something incorrect about DNA's charge.	Response explains that DNA will not move in gel or will move out of top of gel; mentions either that DNA is negatively charged OR mentions that DNA is attracted to the positive	Response explains that DNA will move out of the top of the gel OR will not move out of the gel, and explains that the negatively-charged DNA is attracted to the positive electrode

<p>5B. You are running a DNA electrophoresis gel and you discover that you accidentally reversed the positive and negative electrodes. What will happen to the DNA that you loaded at the top of your gel? Explain.</p>	<p>No response or completely incorrect response</p>	<p>Response mentions that DNA is negatively charged, OR that DNA is attracted to the positive electrode, but does not explain how DNA will move.</p>	<p>Response explains that DNA will not move in gel or will move out of top of gel without mentioning that DNA is negatively charged OR saying something incorrect about DNA's charge.</p>	<p>Response explains that DNA will not move in gel or will move out of top of gel; mentions either that DNA is negatively charged OR mentions that DNA is attracted to the positive electrode, but not both.</p>	<p>Response explains that DNA will move out of the top of the gel OR will not move out of the gel, and explains that the negatively-charged DNA is attracted to the positive electrode</p>
<p>6A. Some diseases are caused by mutations. What in the cell is mutated? Briefly describe three types of mutations that might occur.</p>	<p>No response, or incorrect or missing explanation of what is mutated and no or incorrect types of mutations listed</p>	<p>Response lacks or has an incorrect explanation of what is mutated (e.g. proteins) but does contain at least one correct type of mutation; OR Response explains that DNA OR genes are mutated in the cell, but fewer than 3 correct types of mutations are listed and defined</p>	<p>Response is one of the 3: 1. States that DNA or genes are mutated in the cell AND 3 correct mutations are listed (w/o correct definitions) OR 2. Says DNA is mutated AND has one correctly listed and defined mutation OR 3. Has 3 correctly listed and defined mutations, but does not say that DNA is mutated.</p>	<p>Response explains that DNA or genes are mutated in the cell AND has 2 correctly listed and defined mutations</p>	<p>Response explains that DNA OR genes are mutated in the cell; 3 of the 6 possible mutations are listed and all three mutations are correctly defined (see below)</p>
<p>6B. On the gel electrophoresis image below are samples</p>	<p>No response or incorrect type of</p>	<p>Response does not correctly identify the deletion mutation but</p>	<p>Response describes CF mutation as a deletion mutation</p>	<p>Response describes CF mutation as a deletion mutation;</p>	<p>Response describes CF mutation as a deletion mutation;</p>

Question 3B:

	B	b
b	Bb	bb
b	Bb	bb

50% or $\frac{1}{2}$ brown eyes Bb = brown; bb = blue

Question 4A: Examples of acceptable PCR steps:

Heating and cooling (listed together)

Multiple rounds/cycles of enzyme action/activity

Multiple rounds/cycles of DNA replication (cannot say “multiple cycles of polymerization”, because that is from question 4B)

Example of 3 steps that clearly define process:

1. Combine DNA with primers
2. Repeated cycles of heating and cooling
3. Cycles of DNA replication

Question 6A: Types of mutations and their correct definitions:

Deletion—nucleotides are deleted from the gene

Insertion or Addition—nucleotides are added to the gene

Substitution or Point mutation—one or more new nucleotides are substituted for the original ones (Point mutation is a substitution of a single nucleotide, but we will accept this definition for both terms)

Inversion—a portion of the nucleotide sequence/gene is flipped around/inverted/rotated 180° in the gene

Frameshift mutation—due to a single nucleotide insertion or deletion, the reading frame of the coding sequence is shifted

Supplementary Table 4. 2012 SLP-related final exam questions and answers.

No.	Question	Multiple-choice answers
1.	Genetic information is stored in:	a.) Nucleic acids c.) Carbohydrates b.) Proteins d.) Lipids
2.	Which of the following is true concerning alleles?	a.) They are alternative forms of a gene coding for the same trait. b.) There are always two alleles for each trait. c.) They are the results of alternative splicing of mRNA. d.) Dominant alleles are found at a greater frequency than recessive alleles.
3.	If a homozygous red-flowered (dominant plant) is crosses with a heterozygous red-flowered plant, the probability that the offspring would have white flowers (recessive) is:	a.) Zero b.) 25% c.) 50% d.) 75% e.) 100%
4.	Purple flowers are dominant over white flowers. If the offspring of two parents are 25% white-flowered, what could be the genotypes of the parents?	a.) PP x pp b.) Pp x pp c.) Pp x Pp d.) PP x Pp
5.	In order to amplify a gene using PCR, it is necessary to:	a.) Know the entire sequence of the gene. b.) Have primers that bind to either end of the region in which the gene is found through complementary base pairing. c.) Obtain DNA from a cell in which the gene is being expressed. d.) Use an enzyme to extract the DNA
6.	In gel electrophoresis, DNA molecules are separated by:	a.) size and charge c.) size only b.) charge only d.) sequence

Supplementary Table 5. 2012 lab-related final exam questions and answers.

Question	Multiple-choice answers	Lab related to question
A hypothesis is:	a.) Is a tentative explanation based on observations b.) Is supported by scientific evidence c.) Not been supported by data d.) The basis of a theory	Multiple labs; <i>Physiology & Homeostasis</i> and <i>Population & Community Ecology</i> specifically discuss and have students formulate their own hypotheses
A prokaryotic cell:	a.) Has a cell wall made of cellulose b.) Lacks internal membranes c.) Contains only single-stranded DNA d.) Cannot live in aerobic conditions	<i>Cell structure and organization</i> : structural differences between prokaryotic and eukaryotic cells
Populations grow until:	a.) All of the environmental resources have been depleted b.) They reach the carrying capacity of the environment c.) The fertility rate declines to just above 2 d.) All of the above	<i>Population & Community Ecology</i> : explanation of carrying capacity, experiment about population growth
The carrying capacity of an environment is dependent upon:	a.) Natural disasters such as fire, wind and flood b.) Disease c.) Food and space d.) Predation e.) All of the above	<i>Population & Community Ecology</i> : explanation of carrying capacity