Supplemental Material

CBE—Life Sciences Education

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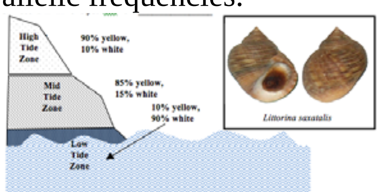
Appendix

In the table below, lesson plans for teaching Hardy-Weinberg principles are outlined for both a non-flipped and flipped approach. Unshaded blocks indicate activities that were done in class; shaded blocks indicated activities done as homework. This unit covered a full week of class (three 50-minute class periods), including three rounds of the learning cycle.

5-E Learning Cycle	**Non-Flipped**	**Flipped**
Engage	Students are introduced to a population of yellow and white flowers living at two opposing altitudes on a mountainside. The alleles in the population are represented by yellow and white pony beads. Students observe the differences between the populations (the flowers are mostly yellow at lower altitudes and mostly white at higher altitudes) and come up with hypotheses to explain the differences they see.	Students visit the course website and access an online assignment. It first introduces them to a population of yellow and white flowers living at two opposing altitudes on a mountainside. The alleles in the population are represented by yellow and white pony beads, of which a picture is  shown. Students observe the differences between the populations (the flowers are mostly yellow at lower altitudes and mostly white at higher altitudes) and come up with hypotheses to explain the differences they see. They enter these hypotheses directly into the assignment.
Explore	In groups of three, students are assigned a sample from one of the two populations and asked to solve the question, What happens to dominant and recessive phenotypes in a population over generations? Students practice drawing alleles from the sample and record phenotype and genotype frequencies. They share alleles with another group from the same population to simulate mating and then draw alleles from the new sample and record phenotype and genotype frequencies. This	Students are asked to solve the question, What happens to dominant and recessive phenotypes in a population over generations? They watch a video of students drawing alleles from the both samples. They are assigned to population #2 and actively record phenotype and genotype frequencies from the beads being pulled from the sample on the video. They watch a simulation of alleles being shared with another group from the same population to simulate mating and then alleles are

	procedure is repeated two more times. Students then use their recorded numbers to estimate the proportion of each allele in the population from which their sample was drawn and to determine if the frequencies change over time. Using the estimated proportion of each allele, students determine the probability of getting each genotype from a random draw from a population and construct the Hardy-Weinberg equation.	drawn again from the new sample. Students again record phenotype and genotype frequencies as they observe them on the video. This procedure is repeated two more times. Students then use their recorded numbers to estimate the proportion of each allele in the population from which their sample was drawn and to determine if the frequencies change over time. They enter these answers into the online assignment. Using the estimated proportion of each allele, students determine the probability of getting each genotype from a random draw from a population and construct the Hardy-Weinberg equation, which is entered into the online assignment.
Explain	Throughout the exploratory activity, the instructor and teaching assistants are circulating about the classroom monitoring progress and offering assistance when needed. Once students have derived equations, the equations are written on the board and discussed as a class until consensus is reached. The instructor then labels the equation as Hardy-Weinberg and explains the purpose and use of the equation.	After each question in the exploratory activity, feedback is given after an answer has been submitted offering explanations and guidance. Once students have derived equations and entered them in, an explanation is given of what the equation should look like and labeling it as Hardy-Weinberg. A brief explanation is then given of its purpose and use followed by a couple questions asking for understanding.
Elaborate	Students are given multiple scenarios involving genetic traits. For each scenario, certain knowns are given and students must use the Hardy-Weinberg equation to find the unknowns. In addition, students are asked to design an experiment to test one of the hypotheses they came up with to explain the differences in the original flower population from class. Answers are given *after* the assignment due date has passed so that students can review them.	Students work in groups of three on scenarios involving genetic traits. For each scenario, certain knowns are given and students must use the Hardy-Weinberg equation to find the unknowns. In addition, students are asked to design an experiment to test one of the hypotheses they came up with to explain the differences in the original flower population from class. The instructor and teaching assistants are circulating throughout the classroom offering guidance where

		needed. Occasionally, the class is brought back together to discuss questions that may be presenting particular difficulty to the students. All answers are revealed at the end of class to ensure that everyone has them before leaving class.
Evaluate	Students take a 4-question clicker quiz asking students to apply the equation in solving simple problems to assess basic understanding. Feedback is given immediately following the quiz.	Students take a 4-question online quiz asking students to apply the equation in solving simple problems to assess basic understanding. Feedback is given immediately upon submission.
Engage	Students are introduced to a species of snail that lives in three different tidal zones and represents three populations that display different allelic frequencies.  	Students visit the course website and access an online assignment where they are introduced to a species of snail that lives in three different tidal zones and represents three populations that display different allelic frequencies (pictured to the left).
Explore	Various scenarios are given to the students wherein the snail population experiences shifts in allelic frequencies, which they simulate with beads. Students use these examples to construct possible causes for a population to shift out of Hardy-Weinberg equilibrium. Students discuss these causes in groups of three and then report out to the class.	Various scenarios wherein the snail population experiences shifts in allelic frequencies are shown via short video clips. Students use these examples to construct possible causes for a population to shift out of Hardy-Weinberg equilibrium. Students enter each explanation in the online homework assignment.
Explain	For each scenario, student directed explanations are put on the board and used to introduce the assumptions of the Hardy-Weinberg model (e.g., that no gene flow, genetic drift, non-random mating, natural selection, or mutation occurs).	Following each explanation submitted, feedback is given wherein each assumption of the Hardy-Weinberg model is explained (e.g., that no gene flow, genetic drift, non-random mating, natural selection, or mutation occurs).
Elaborate	Students visit the course website and access an online assignment where they are given several scenarios of human populations	Students work in groups of three on several scenarios of human populations with varying susceptibility to Malaria contingent

	with varying susceptibility to Malaria contingent upon several different mutations to hemoglobin genes. Students calculate genotype and phenotype frequencies, hypothesize possible causes for differences in frequencies between populations, and identify assumptions that have been violated. All responses are entered into the online assignment followed by explanatory feedback after submission.	upon several different mutations to hemoglobin genes. Students calculate genotype and phenotype frequencies, hypothesize possible causes for differences in frequencies between populations, and identify assumptions that have been violated. Each scenario is worked on first in groups and then shared out in a class discussion led by the instructor.
Evaluate	Students take a 4-question clicker quiz wherein they solve problems using the Hardy-Weinberg equation and they determine which assumptions have been violated in given scenarios. Feedback is given immediately after the quiz.	Students take a 4-question online quiz wherein they solve problems using the Hardy-Weinberg equation and they determine which assumptions have been violated in given scenarios. Feedback is given immediately after submission.
Engage/ Explore/ and Explain	Students participate in an interactive class discussion tying principles learned in the last two class periods together. Two scenarios are given where populations of organisms experience events that not only change allele frequencies but lead to potential speciation events. Students hypothesize possible working definitions for species and then test them on several scenarios. Students also explore the different patterns of natural selection using authentic examples (e.g., stabilizing, directional, and diversifying).	Students visit the course website and access an online assignment where they interact to tie principles learned in the last two class periods together. Two scenarios are given where populations of organisms experience events that not only change allele frequencies but lead to potential speciation events. Students hypothesize possible working definitions for species and enter them into the assignment. After feedback is given, they test them on several scenarios. Students also explore the different patterns of natural selection using authentic examples (e.g., stabilizing, directional, and diversifying) answering various questions testing for understanding and receiving feedback.
Elaborate	Students apply what they have learned about Hardy-Weinberg equilibrium, assumptions, and types of natural selection to two unique scenarios: (1) a case of the	Students apply what they have learned about Hardy-Weinberg equilibrium, assumptions, and types of natural selection to two unique scenarios: (1) a case of the

	increased frequency of a rare genetic disease (fumaric acidurea) in a small polygamist population in Colorado City, and (2) determining the meaning of 'race' in human populations. Students read scenarios, analyze data, and answer questions pertaining to each scenario. Answers are entered into the online assignment and feedback is given upon submission of each answer.	increased frequency of a rare genetic disease (fumaric acidurea) in a small polygamist population in Colorado City, and (2) determining the meaning of 'race' in human populations. Students work in groups of three facilitated by the instructor and teaching assistants. They read scenarios, analyze data, and answer questions pertaining to each scenario. Each question is discussed first in their groups and then as a class.
Evaluate	Summative assessment of this unit is included on the unit exam.	Summative assessment of this unit is included on the unit exam.