Advances in Biology Laboratory Education
Publication of the Association for Biology Laboratory Education
Volume 42, Article 18, 2022

Using a Semester Long Theme to Build Connections of Big Concepts

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In theory, students will have a better understanding of concepts when there is an overall theme linking them. Over 12 weeks, students participated in a fictitious research team that studied melanin, a pigment found in the skin of most eukaryotic species as well as various prokaryotic species. Students studied the production of, the influence of, and the absence of melanin all while linking it to basic biology concepts such as gel electrophoresis, recombinant DNA, bacterial transformation, evolution, natural selection, animal diversity, immunology, mammalian anatomy, and ecology. Students went from the building blocks of DNA that are involved in the expression of the TYR gene through natural selection all the way up to its ecological impact. Each week, two student research teams (Alpha and Beta) gathered information and sent back conclusion letters to the fictitious offshore research lab. Students were also asked to complete micro-credentials, or training sessions, to earn badges to be allowed to access the lab exercise assigned for that day. This pilot study was designed for both in-person and virtual learning but could be adapted to fully online or fully in-person if needed.

Keywords: themes, melanin, digital badges, student engagement, protein synthesis, albinism

Introduction

Students within an introductory biology lab learn about various topics over a single semester. Unlike lecture, which usually meets with students multiples times during the week, students typically meet for lab once a week for a set period of time. Once that time elapses, the following week starts a new topic. Usually, there is no carryover of topics from one week to the next and very rarely is the same topic discussed over multiple weeks.

A thematic unit connects ideas, concepts, themes, subthemes, and focus questions together to form a large intercorrelate structure. The connection of ideas and concepts enhance the brain-seeking pattern strength (Lynch 2021; Davies and Brown 2011) and could increase critical thinking skills. Lynch (2021) states that thematic units boost student interest, increase student engagement and promote connections from real world experiences.

During the Spring 2021 semester, a pilot study was put together to investigate whether students were able to grasp a better understanding of concepts by being involved in a semester long theme, an emerging pedagogical term known as thematic learning. At the start of their first lab, students were informed that they were going to be a part of a fictitious research team that was studying melanin for an offshore research lab. Students were told that each week, the lab will send them investigations and require that they, the student, send back a conclusion letter outlining their results.

Micro-credentials and Badges

Prior to the start of lab exercises, students were required to complete prelab material to earn digital badges. A digital badge is an online, visual graphic that holds metadata that can help explain to the recipient the context, meaning, process and result of the award (Gibson et al. 2015). The purpose of the digital badge is a visual cue to indicate that a training session had been successfully completed. A weekly checklist, made up of different categories, was supplied by a faculty member. This checklist included suggested readings, instructional/informational videos, and sometimes simulations. Faculty also include in this last section a ten-question quiz to assess student knowledge and understanding of the material they read, watched and/or simulated.

There was a total of 12 digital badges available to be earned by students. Students needed to complete the checklist in the learning management system (LMS) as well as completing one attempt on the quiz. Quizzes were automatically graded and students had unlimited attempts while the quiz remained open. Quizzes were permanently closed 1 week prior to the end of the semester.

Overview of the Different Labs

Covid-19 restrictions required students to socially distance (maintain 6 ft apart). Class sizes over 12 were split into two groups, Alpha and Beta, to accommodate restrictions. Students met in the lab during their allotted time slot, while students with ADA accommodations attended the lab virtually.

The first week of the semester (lab zero) was an introductory lab and was not included below in the description of the 12 labs. The last lab was the student's final exam. For most labs, students had an activity that was not based on melanin. Students used their critical thinking skills as well as provided information from the previous activity to help them complete any melanin activity.

Lab One- Investigation of pigmentation through gel electrophoresis (virtual)

Assignment #1: Students will complete a gel electrophoresis lab looking at different dyes. The purpose of this assignment is for students to identify different dyes based on molecular mass and charge.

Assignment #2: Students will examine three different types of melanin. Based off molecular weight only, student will place the three pigments on a paper gel, making sure to label the anode and cathode. Students will then write up a conclusion letter.

Lab Two- Recombinant DNA: Inserting TYR gene into a plasmid (virtual)

Assignment #1: Students will look at model DNA, cut them with restriction enzymes and run them on a paper gel to show fragment size.

Assignment #2: Students will take what they learned about restriction enzymes and apply it. Students are given the materials to create a ring of plasmid DNA (paper) and inserted it into it the TYR gene using the proper enzyme. Students will then write up a conclusion letter.

Lab Three- Bacterial transformation: Growing tyrosinase (virtual)

Assignment #1: Students will be given cards that display different steps of bacterial transformation. Using Google Jamboard (a digital interactive whiteboard), students put the cards in order to properly transform bacteria. The purpose of the lab is for students to take the plasmid created from last week and simulate inserting it into *E. coli*.

Assignment #2: Students will review the virtual results and interpret them. Students then calculate the transformation efficiency and will then write up a conclusion letter, answering three questions within the letter.

**Lab Four- Genetic investigation of OCA1 due to a frameshift mutation (student handout and instructor notes provided)*

Assignment #1: Students will practice protein synthesis through paper models of DNA, mRNA, tRNA and amino acids. Students will then fill out a worksheet to complement the models.

Assignment #2: Students will analyze a set of DNA displaying a frameshift mutation, which caused a baby cow to lack pigmentation. Students will then write up their conclusion letter based on the scenario.

Lab Five- Natural selection of rock pocket mice coat color

Assignment #1: Using a lab already designed by the Howard Hughes Medical Institute (HHMI), students will discuss the MC1R gene controlling coat color instead of the TYR gene.

Lab Six- Applying the Hardy-Weinberg principle to coat color of rock pocket mice (virtual)

Assignment #1: Using another HHMI lab, students will reinforce concepts of variation and natural selection by applying the Hardy-Weinberg equation to real data collected on rock pocket mouse populations.

Assignment #2: Students will then write up a conclusion letter explaining which fur color has the greatest overall selective advantage as well as describe what environmental change gave a selective advantage for one coat color over another.

Lab Seven- Immunology investigation using an ELISA test for vitiligo in dogs

Assignment #1: Students will use an ELISA kit purchased through Carolina Biological to test 6 "patients" for antibodies. A positive result signals that the dog patient has canine vitiligo. In this scenario, canine vitiligo is an autoimmune disease. Students will then write up a conclusion letter.

Lab Eight- Investigation of melanin producing bacteria through mock gram staining (virtual)

Assignment #1: Students will practice gram staining steps on Google Jamboard and then discuss bacteria shape and motility.

Assignment #2: Students will then read seven sample descriptions and match the descriptions with bacteria images (labeled A-H). Among those seven bacteria, students learn that a few can naturally produce melanin. Students will then write their conclusion summary on what they learned, and describe from which bacteria they would pick to extract melanin and why.

Lab Nine- Animal diversity investigation for albinism exhibit

Assignment #1: Students will walk around a lab room that holds various specimens. Students will have to record body plan, body symmetry, phyla and common name as well as distinguishing characteristics.

Assignment #2: Students will then design a zoo exhibit based on a set of given albino organisms. Students will need to group their organisms and describe common characteristics. Students will then write up a conclusion letter.

Lab Ten- Melanin and organ identification during mammalian dissection

Assignment #1: Students will investigate if pigmentation has an effect on lung/heart size. Students will be given either a brown or white mouse. They will label their mouse's external and internal features, cut out and weigh the heart and lungs of the mouse and then calculate the ratio of organ weight to body size. Students will then graph the class data.

Assignment #2: Students will complete a conclusion letter while answering the following questions: Was there a size/weight difference between the organs in the mice; If there was a significant difference in albino mice (either larger or smaller), physiologically, how would that affect the mouse; and would this be useful to scientists?

Lab Eleven- Serengeti Rules (asynchronous)

Assignment #1: Students will watch *The Serengeti Rules, a one hour long PBS nature long show (*https://www.pbs.org/video/the-serengeti-rules-41dfru/) and write a reflection based on what they have learned about melanin so far. Grasping that the main concept was about a keystone species, student responses can vary from importance of camouflage in a predator/prey relationship to impact on the possible loss of pigmentation.

Lab Twelve- Ecosystems and biomass

Assignment #1: Using a game that was adapted from whale Jenga from the Cabrillo Marine Aquarium (http://www.cisanctuary.org/ocean-acidification/PDFs-WorkshopPage/Whale%20Jenga%20A%20Food%20Web%20Game_October_2015.pdf), students will play ecosystems Jenga based on a local food web. Student will also answer questions.

Assignment #2: Students will then read about a genetic variation due to the MC1R gene in Eastern Gray Squirrels. They will then take what they have learned from the ecosystems Jenga game and apply it to their final conclusion letter.

Discussion

After the 12 weeks of instruction, students commented that they enjoyed the way the lab was taught. The majority of students remarked that a theme (whether it is melanin or something different) should be used. Because an IRB was not obtained prior to this pilot study, student survey data is not able to be provided.

Part two of the pilot study is set to take place during the Spring 2022 semester and will include student survey data as well as more stringent requirements for earning the digital badges. Virtual labs that were in place due to covid will also be adapted to face-to-face materials.

Sample Student Handout

On the following pages you will find one example of the labs that was taught and how melanin was incorporated into the second activity. This lab exercise was taught virtually due to the Covid-19 pandemic but can be easily converted to face-to-face (see notes for instructor). Materials and notes for the instructor are also for just the one lab described below. For additional labs and information, feel free to email the author.

Student Outline

Lab 4
Student Handout: Genetic Investigation of OCA1 Due to a Frameshift Mutation

Last week, the lab sent you a plasmid and you "grew" colonies of transformed bacteria. The plasmid contained the TYR gene that coded for the enzyme tyrosinase. This week your research team is investigating a frameshift mutation within the TYR gene. This frameshift mutation can be seen in multiple organisms. In humans, the mutation causes the reduced production of melanin and is classified as type one oculocutaneous albinism (OCA1). This recessive genetic disorder is a rare disorder (1/20,000) of melanin biosynthesis and needs to be studied further. This particular gene mutation is found on chromosome 11. The reduced pigmentation is called hypopigmentation and can be seen displaying reduced pigmentation in the iris and retina as well as reduced melanin production in skin and hair. You will be looking at bovine blood samples.

This week you will be working remotely. This will be a longer lab and both team Alpha and team Beta will meet together virtually. You will first complete a practice exercise of protein synthesis using paper models. All models should be cut out prior to lab. Once you have completed your practice model and submitted your work, you can move on to the next task. You will be given the coding strand of DNA for part of the TYR gene sequence that is said to contain the frameshift mutation. You will compare the amino acids in the original TYR gene sequence with that of the mutated gene. You will need to write up in a report to your Team Leader why this mutation is significant.

Weekly Learning Objectives:
- You will know the different base pairs for DNA and RNA
- You will understand the relationship between genes, proteins, and codons
- You will know where transcription and translation take place
- You will be able to demonstrate the process of transcription and translation
- You will be able to correctly use terminology such as RNA polymerase, mRNA, DNA template strand, codon, tRNA, ribosome
- You will understand the effects of a frameshift mutation

This Weeks Learning Style: Virtual Only, Synchronous Zoom Session, 1hr 50 minutes

Virtual Learning Procedure:
- Use the link that was given to you on week one and log into the Zoom session at the start of the lab. Do not be late and keep your camera on.
- The lab will begin by making sure that everyone has completed their training and answering any questions.
- You will then follow along with the class and complete Activity #1. Activity #1 and #2 should be printed out prior to the start of lab.
- Once complete submit assignment #2 to your LMS.
- The class will then be put into breakout rooms and you will complete and submit Activity #2 with your team.
- You can leave the Zoom session once you have submitted your completed assignments or the 1 hour and 50-minute allotted lab time has expired, whichever comes first.

Assignment #1: Protein Synthesis

This activity is designed to model how DNA is responsible for the synthesis of particular proteins based on the sequence of amino acids bound together by peptide bonds. You will need to pick up the appropriate models ahead of time. When you are finished with your models, please return them to your instructor.

Procedure:

- Your team leader will go through the steps of protein synthesis with large magnetic models.
- You will then use your models and complete the chart below. Once you have completed the chart, move on to part two.
- When you have completed parts two and three, you will submit your work to your LMS.

Part One: Fill out the chart below. When filling in the boxes, write the nucleotides in sets of three. Writing it this way will help you later when figuring out the correct codon.

Template #_____ (Found on the top of the red DNA template Strand, 3' to 5')

DNA Coding Strand (red- runs 5' to 3')					
Template Strand (red- runs 3' to 5')					
mRNA codon (green- runs 5' to 3')					
tRNA anti-codon (blue)					
Amino Acid (yellow)					

Part Two: In your reading, you have learned about different types of mutations. A common small-scale mutation affects one or a few nucleotides. Sickle-cell anemia is a disease in which a single nucleotide has been affected on the template strand. Fill in the tables below to see which amino acid was changed due to this mutation. Then circle which amino acid mutated.

A portion of normal red blood cell sequence:

DNA Coding Strand	**GTG**	**CAC**	**CTG**	**ACT**	**CCT**	**GAA**	**GAG**	**AAG**	**TCT**
Template Strand									
mRNA codon									
tRNA anti-codon									
Amino Acid									

A portion of sickle-cell red blood cell sequence:

DNA Coding Strand	**GTG**	**CAC**	**CTG**	**ACT**	**CCT**	**GTA**	**GAG**	**AAG**	**TCT**
Template Strand									
mRNA codon									
tRNA anti-codon									

Amino Acid									

Part Three: People who are homozygous for a specific mutation, delta F508, tend to have the most severe symptoms of cystic fibrosis due to critical loss of chloride ion transport. This upsets the sodium and chloride ion balance needed to maintain the normal, thin mucus layer that is easily removed by cilia lining the lungs and other organs. The sodium and chloride ion imbalance creates a thick, sticky mucus layer that cannot be removed by cilia and traps bacteria, resulting in chronic infections.

A piece of genetic code for Cystic Fibrosis reads 5'ATC ATC TTT GGT GTT 3' (assume this code is from the coding strand). Due to a deletion of three nucleotides CTT, the new genetic code reads 5'ATC ATT GGT GTT 3'. Roughly 70% of mutations observed in Cystic Fibrosis patients result from a three nucleotide deletion in CFTR's nucleotide sequence.

- As a result, this deletion results in the absence of the amino acid ___________, located at position 508 in the protein. Make sure to show all work on how you got your answer.

Assignment #2 Protein Synthesis

Frameshift Mutation of the TYR Gene: This week you have been asked by your team leader to look at two small pieces of DNA. The first sample was a snippet of code from an organism that exhibits albinism, specifically a Braunvieh heifer (Schmutz et al., 2004). The second snippet of DNA will be from an organism of the same species without any pigmentation mutation.

Procedure:

- You are given the following DNA sequence: 3' TCTGGCCGTGGCTCATTGGGGCCCGGG 5'. This DNA sequence is from a normal Braunvieh heifer. The second sample is from an albino Braunvieh heifer. Due to the insertion of 1 nucleotide, the new code reads 3' TCTGGCCGTGGCTCCATTGGGGCCCGG 5'.
- Once you have completed the two tables below, circle the added nucleotide and then circle the affected amino acid(s) that is/are likely to be responsible for the reduction in melanin production.

A portion of the normal Braunvieh heifer sequence:

DNA Coding Strand									
Template Strand									
mRNA codon									
tRNA anti-codon									
Amino Acid									

A portion of the albino Braunvieh heifer sequence:

DNA Coding Strand									
Template Strand									
mRNA codon									
tRNA anti-codon									
Amino Acid									

Conclusion Letter: Once you have gone through the activity, you will need to write a brief letter to your team leader explaining your results.
You should also include:

- What part of the DNA strand did you see the mutation?
- What amino acid sequence was altered as a result?
- What is the relationship between the TYR gene and melanin?
- What impacts does this change have on the organism?

See the sample letter below. The following is just an example and does not need to be written word for word.

(Insert team leader name) <--- this would be your professor's name
Melanin Scientific Research Team
263 Alden Street
Springfield MA 01109

Dear (insert team leader name here),

My team spent the week researching protein synthesis and was able to model protein synthesis from DNA to a chain of amino acids. I feel confident about my results. Based on (give 1-2 reasons here), I feel confident that (give answers to questions above here).

Sincerely,
(insert name here)
(insert section here)

Cited References

Schmutz SM, Berryere TG, Ciobanu DC, Mileham AJ, Schmidt BH, Fredholm M. (2004) A form of albinism in cattle is caused by a tyrosinase frameshift mutation. Mamm Genome. 15(1):62–67.

Materials

A Protein Synthesis Manipulatives Kit (Carolina Biological, item # 211111, ~$325.25) is required for the first part of the lab. Within the kit, there should be enough mini-models for each pair students within a small class (~24 students). Students should also be given a dry erase marker or china and glass pencil to write on the mini-models as well as a copy of a genetic code table. LCD projector and computer are required for faculty for any lab discussion and review of background information. This lab is designed to take 2 hours.

Notes for the Instructor

In this multi-part activity, faculty will first demonstrate protein synthesis using the large models provided in the kit. Students are encouraged to participate. (It is at the discretion of the faculty member whether or not a review of DNA, RNA, transcription and translation are needed. If so, a PowerPoint should be shown first.) If virtual, students are asked what each of the models represent (i.e. DNA, nucleotides, mRNA, tRNA, ribosome, amino acids) and what the next step is. If face to face, large model pieces are handed out to the class. As the faculty member needs them, students are called up.

Students then complete a practice exercise of protein synthesis using paper models. If virtual, these models are supplied to students ahead of time and are then returned by the student (faculty can have a sign in/sign out system). If students are face to face, the models are put in clear ziplock bags and given out/collected during each class (if there are multiple sections). There are 4 different model templates (indicated on the template DNA strand) and multiple copies of the 4 templates. If lab is virtual, it is suggested that faculty put students into breakout rooms to complete assignment #1. Answers to the first assignment are supplied with the kit. If face to face, students can work in pairs.

Once students have completed the paper model and submit their work either to the faculty member or to their LMS, faculty will then guide students onto assignment #2. If virtual, students can either work in one big group or in breakout sessions. If face to face, students can work within groups of 2-4. Faculty will introduce the activity by explaining that there is a baby cow born very different from both parents. It is exhibiting albinism. It is the student's job, assigned by the Melanin Research Team, to investigate a snippet of DNA that could be the reason for the color difference.

On assignment #2, students will analyze part of the TYR gene sequence (coding strand of DNA) that is said to contain a frameshift mutation (if students are not familiar with frameshift mutations, now is a good time to review). Students will take what they have learned from assignment #1 and compare the amino acids in the original TYR gene sequence with that of the mutated gene sequence of the baby cow. Students will then write up a conclusion letter to the offshore research lab (aka faculty member in charge of the lab) as to what they found and why this mutation is significant.

Once students have figured out that it is mainly a stop codon that causes the reduced production of melanin, you can explain that:

A premature stop codon in the TYR gene sequence in albino Braunvieh calves is also a cause of albinism in humans, known as oculocutaneous albinism I (Tomita et al. 1989). A premature stop codon would eliminate one of the two copper-binding sites in the TYR gene sequence and therefore would likely have major effects on the function of the tyrosinase produced. Spritz et al. (1997) showed that each of the six histidines was necessary for binding the two Cu++ ions, and that the loss of the Cu++ binding caused albinism in the mutated cell lines studied.

Prior to lab, faculty should decide what prelab material is important for the student to complete before the start of lab.

The checklist for this lab included:

Read:

1. RNA's Role in the Central Dogma (https://learn.genetics.utah.edu/content/basics/centraldogma/)
2. Genetic Code Table (any image will do)
3. Protein Synthesis Visual (an overall image will do)

Watch:

1. DNA Transcription (Basic) (https://youtu.be/5MfSYnItYvg)
2. mRNA Translation (Advanced) (https://youtu.be/TfYf_rPWUdY)

Do:

1. Online Weekly Quiz

By completing the above checklist, students earn a training certificate and digital badge for lab 4 (see introduction for more detail). The badge and certificate can be set up through the LMS (the author used D2L Brightspace) or through badgr.com. If the latter, students will need to create an account.

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Acknowledgments

Thank you very much to Sara LaTorra, Lorie Woodson and those in the Biology/Chemistry department that helped me over the past year. This theme and all the labs within it couldn't have come together without all your insight and support. I would also like to thank the attendees during the June 2021 ViABLE workshops. I appreciate all the provided feedback.

About the Authors

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Citing This Article

Gemma B. Bartha. 2022. Using a Semester Long Theme to Build Connections of Big Concepts. Article 18 In: Boone E and Thuecks S, eds. *Advances in biology laboratory education*. Volume 42. Publication of the 42nd Conference of the Association for Biology Laboratory Education (ABLE). https://doi.org/10.37590/able.v42.art18