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Introductory Cell Biology in a Pandemic – Adaptations for Remote Laboratory Delivery

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The COVID-19 pandemic hit hard and fast, requiring post-secondary institutions to rapidly remodel to maintain learning opportunities. This task has been especially difficult for experiential learning in the laboratory. For many institutions, including our own, in-person delivery of many offered laboratories was not feasible. Consequently, for Fall 2020 and Spring 2021 semesters, we developed and piloted comprehensive laboratory kits that enabled students to perform five of ten experiments typically offered in our introductory cell biology course from their homes without need of specific scientific equipment. The laboratory kits are inexpensive ($10 CAN each), safe and require students to provide only common household items to supplement their kit. We present an overview of the lab activities developed and reflect on student learning outcomes and evaluations from the previous year. We also provide one of our developed remote activities that examines cell membrane stress, using beet betacyanin as a membrane stress indicator.

Keywords: Remote student learning, laboratory kits, cell membranes

Introduction

The University of Lethbridge is one of the top ranked (in the top three) undergraduate education and research universities in Canada (https://www.ulethbridge.ca/about/facts). It is a small (approximately 8,900 full time students) university located in the city of Lethbridge, southern Alberta, Canada. We attract students from larger centers such as Calgary, as well as many rural communities.

Biology 1010, Principles of Cell Biology is our introductory cell biology course. Approximately 500-600 students take this course every year. This course is core for students majoring in biology, biochemistry, neuroscience, environmental science, and kinesiology, resulting in a diverse cohort of students each term.

Goals of Biology 1010 Labs

As many of our first-year students come from smaller high schools with limited lab budgets, one of our primary goals is to put students at ease and help them become comfortable being in a laboratory setting. This step in the scientific learning process is essential to success in undergraduate science programs, as it is recognized that active learning, as implemented in hands-on laboratories, is perhaps more effective than lecturing in student learning in STEM fields (Freeman *et al*, 2014).

We introduce students to a number of skills that are fundamental to biology, including techniques such as pipetting, microscopy, handling microorganisms, and using spectrophotometers. Students also hone their collaboration skills by participating in group work, develop their time management skills with structured laboratory time points and are introduced to data manipulation and management through the use of collective data – a skill that many students are not comfortable with in their first year of university. Additionally, we introduce students to the scientific process including hypothesis

development, experimental design, and introduce scientific writing.

As discussed above, the laboratory exercises in Biology 1010 emphasize practical skills and reinforce the main biological concepts taught in the lecture component of the course. There is a focus placed on cellular organization, hierarchy and the properties and functions of the major biological macromolecules: nucleic acids, proteins, carbohydrates, and lipids. Both the lecture material and the laboratory techniques taught in the Biology 1010 course are fundamental to students' university careers and as such are built upon in our second- to fourth-year biology courses. Many of the exercises and skills learned in Biology 1010 laboratories transfer well to other scientific disciplines and provide an excellent foundation for the comprehension and implementation of the scientific process.

COVID-19 and the Shift to Online Learning

The COVID-19 pandemic forced an early end to our biology teaching labs for the Spring 2020 semester and required our university to rapidly shift to online learning. Given the importance we place on the experiential learning aspect of teaching labs, and, having the time to plan ahead for the Fall 2020 term, we made the decision to pilot take-home laboratory kits. We thought the ability for students to experience some applied laboratory techniques was essential to their success in what we hoped would be an in-person second-year.

The challenges for executing this plan were several-fold as we had to balance: (1) student safety, (2) feasibility of experiments, (3) cost of the kit materials and (4) the logistics of acquiring and distributing the lab kit materials during a pandemic. These key points helped shape the contents included within the take-home kits, along with their utilization in experiments throughout the term.

Take-home Biology Laboratory Kits

After examining the set of ten student laboratories normally offered in Biology 1010, we identified five of these that could be adapted to be carried out remote from a laboratory, using only common household items or laboratory consumables, without posing any more hazard than typical meal preparation. The developed labs included activities that examined:

1. Membrane stress (described in detail in the following sections);
2. Cellular respiration – using imbibed mung beans;
3. Enzyme activity – with baker's yeast and hydrogen peroxide;
4. DNA structure – via extraction of strawberry DNA and online activities;
5. Food microbiology – through the preparation of homemade yogurt.

These five lab activities were able to touch on the goals of Biology 1010 by focusing on the structure and function of the major biological macromolecules and allowed students to work with digital bench-mates, practice experimental procedures, as well as collect, report and analyze their own scientific data.

Materials for the laboratory kits were mailed to students prior to the start of scheduled laboratory sessions. Experiments were scheduled to run during each two-week period of the course, where the students were tasked with carrying out one of the home lab activities.

We delivered content both synchronously and asynchronously, as flexibility has been seen as one of the keys to successful remote delivery (Garcia-Vedrenne *et al*, 2020). We used Zoom® to deliver pre-laboratory lecture material and host synchronous laboratory sessions as evidence suggests that videoconferencing is an effective tool for lecture delivery (although perhaps not a replacement for traditional lectures) (Pitcher *et al*, 2000). We were able to maintain our usual ratio of students to laboratory instructors for the course and so were able to coordinate group work and assigned discussions in our synchronous Zoom® sessions. Pre-laboratory lectures were recorded using Zoom® and then uploaded to Moodle® via YuJa® for student review. These lectures were supplemented with previously recorded videos demonstrating the relevant procedures for that weeks' experiment. Students were responsible for submitting their experimental data within certain time frames, which was compiled by instructors for students to analyze for their assignments. Additionally, Moodle®, Campuswire®, Jamboard® and Crowdmark® were employed to improve student-instructor communication, as well as to collect and distribute class data and for assessment.

In this ViABLE major workshop we discuss our strategies, logistics, and metrics for a successful implementation of remote first-year cell biology laboratory exercises. We include details of one of the five adapted laboratory activities in a synchronous format that mimics the students' experience and review student feedback to assess the quality and success of learning the core course concepts, as well as the feasibility of performing the experiments, in a home setting. While only one of the five developed take-home lab activities are discussed here, we encourage any individual that is interested in learning more about the other activities to contact the authors.

Student Outline

Remote Laboratory to Examine Membrane Stress

Background

Cellular membranes separate and organize chemicals and reactions within cells by allowing **selective** passage of materials across their boundaries. They are composed of a bilayer of **phospholipid** molecules interspersed with **protein** molecules. In addition, most membranes also contain very small amounts of **carbohydrates** that are usually associated with the phospholipids or proteins. Phospholipids are composed of a phosphate group, glycerol backbone, and 2 fatty acid chains (Figure 1). They are **amphipathic**; that is, each molecule has a **hydrophilic** (water-associating) region and a **hydrophobic** (water-avoiding) region. The charged (polar) phosphate group and glycerol group of each molecule are hydrophilic and the nonpolar lipid tails (fatty acids) are hydrophobic.

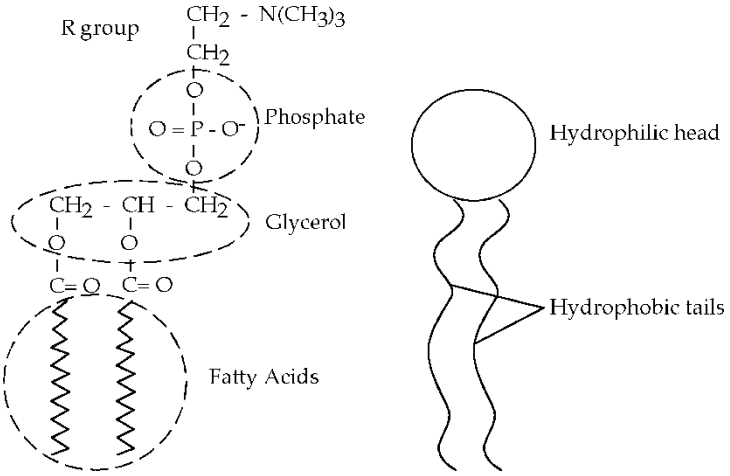

Figure 1. The structural formula (left) and symbolic representation (right) of a phospholipid molecule.

When phospholipids spontaneously assemble in an aqueous solution, the most stable conformation is to have the molecules aligned so that the hydrophobic lipid regions turn inward and face each other, thereby avoiding contact with water (Figure 2). The polar phosphate head regions are arranged outwardly where they are in contact with water. Although the hydrophobic forces holding phospholipids in a membranous structure are individually weak and allow substantial movement of individual molecules, collectively they confer considerable stability to the overall structure.

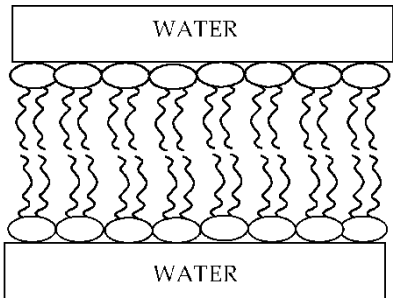

Figure 2. Artificial membrane cross section depicting the orientation of phospholipids when exposed to an aqueous solution.

Interspersed within the membrane are protein molecules. Each protein molecule is folded so that charged hydrophilic amino acid groups project into the aqueous phase inside or outside the cell and uncharged hydrophobic groups contact the inner lipid phase of the bilayer (Figure 3). As with any protein, relatively weak hydrogen bonds hold the membrane proteins in specific folded conformations. Within the membrane, proteins are not fixed in position but rather are free to move about. The proteins within the membrane perform a variety of functions including transport, enzymatic activity, signal transduction, and intercellular joining.

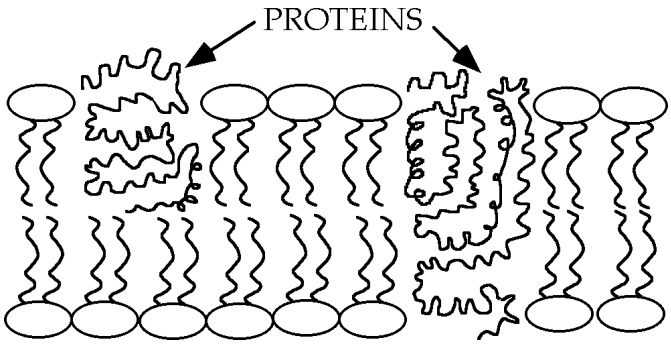

Figure 3. Lipid bilayer found in all biological membranes with embedded proteins.

The physical and chemical integrity of a membrane is crucial for proper functioning of the cell or organelle of which it is a part. The permeability of a membrane is directly related to its phospholipids and transport proteins. In this exercise, we will be studying membranes by looking at the effects of various stresses (temperature and isopropanol OR acetic acid concentration) on beet-cell-membrane integrity, and study how loss of membrane integrity leads to loss of membrane functionThe roots of beets (*Beta vulgaris*) contain an abundant red pigment called betacyanin, which is localized almost entirely in the large central vacuole of beet cells. These vacuoles are surrounded by a vacuolar membrane and the entire beet cell is further surrounded by a plasma membrane. As long as the cells and their membranes are intact, the betacyanin will remain inside the vacuoles. However, if the membranes are stressed or damaged, betacyanin will leak through the membranes and produce a red color in the water surrounding the beet tissue. The intensity of this red color will allow you to assess the damage produced by experimental treatments.

The objectives of today's exercise are thus to:

- Learn about the function of selectively permeable membranes
- Investigate the connection between membrane structure and function by examining the effects of temperature and acid OR isopropanol treatments on membranes of beet cells

Prelab Exercise:

- Prepare hypotheses for the effect of temperature, vinegar (acetic acid) concentration, and isopropanol concentration on beet cell membranes
- Identify in each case the independent and dependent variables, and a minimum of 2 controlled variables
- Prepare a flow chart of the activity
- Upload your prelab work on Moodle®

Supplies Provided: Ruler, test tubes (15 mL Falcon tubes with lids), rack, card with colors and corresponding absorbance values, thermometer, plastic Pasteur pipettes, labels, wooden skewer

For students to supply:

- White vinegar OR rubbing alcohol (needed for the DNA exercise. Note: a minimum concentration of 70% isopropanol is required)
- Microwave or kettle (some way to boil water safely)
- Red beet
- sharp knife, cutting board
- mug
- spoon
- Fridge and freezer
- Tap water
- Timer/stopwatch
- Pen or marker for labelling
- Paper towel

Procedure: You will be examining the effects of **two** different stresses on beet cell membranes. The first stress is temperature (part A). For the second stress, you may choose to test EITHER acetic acid concentration (Part B) using white vinegar (5% acetic acid - a commonly used cleaning product) OR rubbing alcohol (70% isopropanol – often used in disinfecting cuts and abrasions. Hand sanitizer typically contains a minimum of 60-70% alcohol) (Part C).

Carry out one procedure at a time.

A. Temperature Procedure:

Prior to getting started, take a regular drinking cup and fill with tap water and let temperature equilibrate to room temperature (between 20-25°C – use the thermometer provided).

NOTE: Instead of trying to set individual timers for each of the times needed, set a stopwatch and record the time on your stopwatch for each time interval for which you need to keep track (for example: If you put your room temperature sample beet into the mug at 11:16, you then need to remove it at 11:19 and place into the tube marked room temperature).

1. Peel beet and cut 10 small beet samples to 1x1x0.5 cm using the ruler (you need 5 samples for temp procedure, and 4 for the acetic acid procedure OR 5 for the isopropanol procedure). **The most important factor here is that all samples are roughly the same size!!!** Careful when cutting

samples! Stack your samples when cutting – take a good look at them to make sure that they are the same size.

*For the rest of your beet sample, you could add to a soup, grate into a salad, or make stovetop pickled beets.

2. Put into a cup or glass and rinse well under running water for 30 s or until your water runs clear. Place the samples on paper towel to dry.

*What is the purpose of this step?

3. In a microwave safe mug (or kettle), bring a cup of water to a boil. Be careful – boiling water can burn!
4. While water is coming to a boil:
    a. Take two beet samples and pat dry. On a plate or dry piece of paper towel, put one sample into the freezer and place the second sample on a piece of paper towel in the fridge. Incubate these samples for 15 minutes.
    b. Using your cup of room temperature water (pre-step 1), put 5 mL of room temperature water into 5 of your 15 mL Falcon tubes (you can use the plastic pipette to get exactly 5 mL in each tube) and label the tubes: 80°°C, 50°°C, 22°°C, 5°C, and -20°C (the 5°C is your fridge sample and the -20°C is the freezer sample).
5. CAREFULLY remove your mug of hot water and let cool to 80°C. To speed this up, you can add some cool tap water.
6. Add one beet sample directly to the 80°C water in the mug. Let the beet sample sit in the water for exactly 3 minutes.
7. Remove the beet sample (using a spoon) and place into the Falcon tube labelled “80°C.” Let it sit in the water in that tube for 15 minutes – make sure the beet is submerged in the water (may need to tap the tube on the counter to make the sample fall down). Gently mix by inverting the tube every 5 min (cap on).
8. Don’t throw out the water! Allow it to slowly cool to 50°C in the mug.
9. While water is cooling:
    a. After the freezer and fridge samples have incubated for 15 mins, remove them and place the freezer sample into the tube labelled “-20°C” and the fridge sample into the tube labelled “5°C.” Cap them and let the beets sit in the water for 15 mins, inverting the tubes every 5 mins.
    b. Using the cup of water at room temp that you set aside at the very beginning of the lab (pre-step 1), place a beet sample into the water and let sit for exactly 3 minutes then remove it and place it into the tube marked “22°C.” Let it sit in the tube for 15 mins, inverting every 5 min.
10. For the hot water, allow it to cool down to 50°C – once you have completed step 9, you can speed up the cooling by adding cold tap water. Add a different beet sample to the 50°C water and incubate for exactly 3 minutes.
11. Remove the beet sample and place into a tube labelled “50°C.” Let that sit for 15 minutes, mixing gently every 5 minutes.
12. After 15 minutes has passed for each temperature (in the tubes of room temperature water), remove beet samples from each tube using the skewer provided and mix gently. Compare the liquid in the tube to the betacyanin reference card provided. Match the color of each liquid sample to the square that is closest in color on the betacyanin reference card and note the corresponding A460 value above. Record the absorbance for each temperature in your lab notebook. Please carry out this comparison inside under artificial light.
13. Take a photograph of your tube results to include in your notebook.
14. Rinse out your tubes so you can use them again for the acetic acid OR isopropanol procedure.

B. Acetic Acid Procedure:

Note: Skip this step if you are using isopropanol and proceed to section **C**.

1. Label 4 of your tubes as follows: 5% acetic acid, 1.67% acetic acid, 0.56% acetic acid, and 0% acetic acid. To create these concentrations, you will be carrying out what is termed a serial dilution as described in the following steps.
2. In the 5% acetic acid tube, add 9 mL of vinegar (using the gradations on the Falcon tube and the plastic Pasteur pipette to get the bottom of the meniscus on the 9 mL line).
3. To each of the remaining 3 tubes, add 6 mL of tap water (again, using the pipette to get it as exact as possible).
4. Using the Pasteur pipette, remove 3 mL of 5% acetic acid from the 5% tube and put into the 1.67% tube. You should now have 6 mL of 5% acetic acid in tube 1 and 9 mL of 1.67% acetic acid in tube 2. Invert the 1.67% acid tube to mix.
5. Again, using the Pasteur pipette, remove 3 mL of the 1.67% acid solution and add it to the 6 mL of water in the 0.56% acid tube. Invert this tube to mix.
6. Using the Pasteur pipette, remove 3 mL of the 0.56% acetic acid and discard into your sink (DO NOT PUT INTO THE 0% ACETIC ACID TUBE!).
7. You should now have 6 mL of solution in each of your 4 tubes
8. Place a beet sample (that has not been used in the temperature procedure) into each of your acetic acid tubes and cap the tube.
9. Gently invert your samples to mix, ensuring each beet is submersed in solution. Let the samples incubate in solution for 20 minutes and gently mix every 5 minutes.
10. At the end of the 20-minute incubation, remove the beet sample using the skewer provided and mix gently. Compare the liquid in the tube to the betacyanin reference card provided. Match the color of each liquid sample to the square that is closest in color on the betacyanin reference card and note the corresponding A460 value above. Record the absorbance for each concentration of acetic acid in your lab notebook. Please carry out this comparison indoors under artificial light.
11. Take a photograph of your tube results to include in your notebook.

C. Isopropanol Procedure

1. Label 5 of your tubes as follows: 70% isopropanol, 35% isopropanol, 17.5% isopropanol, 8.75% isopropanol, and 0% isopropanol. To create these concentrations, you will be carrying out what is termed a serial dilution as described in the following steps.
2. In the 70% isopropanol tube, add 10 mL of isopropanol (using the gradations on the Falcon tube and the plastic Pasteur pipette to get the bottom of the meniscus on the 10 mL line). Note: if you are starting with > 70% isopropanol, instead add the appropriate amount of isopropanol solution to tap water to have a final concentration of 70%. *E.g.*, if starting with 99% isopropanol, add 7 mL of isopropanol and 3 mL of tap water to your first tube.
3. To each of the remaining 4 tubes, add 5 mL of tap water (again, using the pipette to get it as exact as possible).
4. Using the Pasteur pipette, remove 5 mL of 70% isopropanol from the 70% tube and put into the 35% tube. You should now have 5 mL of 70% isopropanol in tube 1 and 10 mL of 35% isopropanol in tube 2. Invert the 35% tube to mix.
5. Again, using the Pasteur pipette, remove 5 mL of the 35% isopropanol solution and add it to the 5 mL of water in the 17.5% isopropanol tube. Invert this tube to mix.
6. Again, using the Pasteur pipette, remove 5 mL of the 17.5% isopropanol solution and add it to the 5 mL of water in the 8.75% isopropanol tube. Invert this tube to mix.
7. Using the Pasteur pipette, remove 5 mL of the 8.75% isopropanol and discard into your sink (DO NOT PUT INTO THE 0% ISOPROPANOL TUBE!).
8. You should now have 5 mL of solution in each of your 5 tubes
9. Place a beet sample (that has not been used in the temperature procedure) into each of your isopropanol tubes and cap the tube.

10. Gently invert your samples to mix, ensuring each beet is submersed in solution. Let the samples incubate in solution for 20 minutes and gently mix every 5 minutes.
11. At the end of the 20-minute incubation, remove the beet sample using the skewer provided and mix gently. Compare the liquid in the tube to the betacyanin reference card provided. Match the color of each liquid sample to the square that is closest in color on the betacyanin reference card and note the corresponding A460 value above. Record the absorbance for each concentration of isopropanol in your lab notebook. Please carry out this comparison indoors under artificial light.
12. Take a photograph of your tube results to include in your notebook.

A **standard curve** is used to determine the concentration of a substance. It is prepared by assaying various known concentrations of the substance you are trying to measure. In our case, we have measured the absorbance of known concentrations of betacyanin to make our standard curve (Figure 4.)

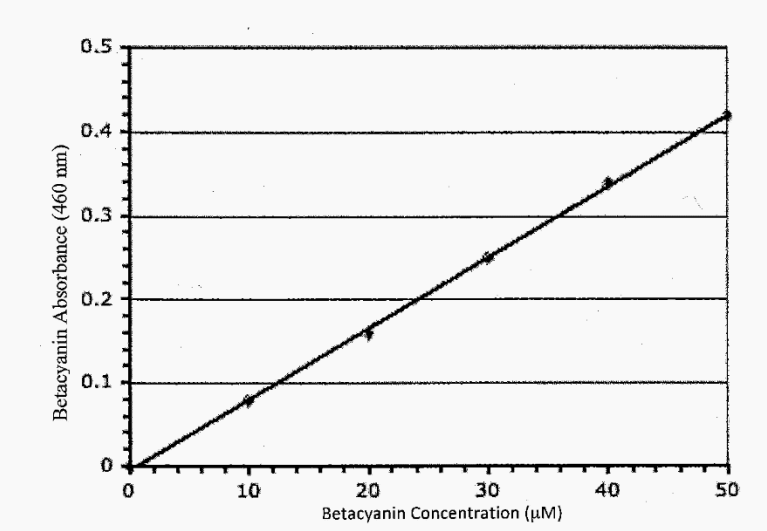

Figure 4. Standard curve for known betacyanin concentrations (*y=0.0084x*)

D. Calculate concentration

1. Use the standard curve provided (Figure 4) to determine the concentration of betacyanin that leaked from the beet cells for each temperature treatment and acetic acid OR isopropanol concentration (your instructor will demonstrate). Record these values in the appropriate table (Table 1, 2 or 3) in your lab notebook.
2. Transfer Table 1, Table 2 OR Table 3 (depending upon the variable you tested) into an Excel® spreadsheet and send to your instructor so they can compile all the class data into one file. Use the class data (received from your instructor) to calculate the means and standard deviations of betacyanin concentration for each temperature treatment, acetic acid concentration OR isopropanol concentration.

Table 1. The absorbance (A_{460}) and concentration of betacyanin leaked from beet (*Beta vulgaris*) cells following different temperature treatments.

Tube #	Temperature (°C)	A_{460}	Concentration (µM)
1	80		
2	50		
3	22		
4	5		
5	-20		

Table 2. The absorbance (A_{460}) and concentration of betacyanin leaked from beet (*Beta vulgaris*) cells following different acetic acid treatments.

Tube #	% Acetic Acid (v/v)	A_{460}	Concentration (µM)
1	5		
2	1.67		
3	0.56		
4	0		

Table 3. The absorbance (A_{460}) and concentration of betacyanin leaked from beet (*Beta vulgaris*) cells following different isopropanol treatments.

Tube #	% Isopropanol (v/v)	A_{460}	Concentration (µM)
1	70		
2	35		
3	17.5		
4	8.625		
5	0		

E. Graphing.

1. Calculate Means and Standard Deviation values from the class data for both experiments performed. See below:
2. Working in Excel® (or another comparable program), prepare two scientific graphs; one demonstrating the relationship between the concentration of betacyanin released and the temperature treatment, and one that demonstrates the relationship between the concentration of betacyanin released and the concentration of EITHER acetic acid OR isopropanol (not both!). You should use the mean and standard deviation values calculated from class data.

Post Lab Exercise

Compare your results to your hypothesis for the experiment. Are your results as expected? Explain.

- Photographs of your results.
- Two completely labelled figures (using class data). Note that the figures should be generated using Excel® or some other spreadsheet program (Open Office® is an example of a suite of programs that do not require purchase).

For the figure illustrating the results of temperature, answer the following (in sentence form, using your textbook as a reference):

- Based on the class results, what temperature(s) were the most damaging to the beet cell membranes? Explain in sentence form using your textbook as a reference.
- Based on the class results, what temperature(s) had little or no effect on the beet cell membranes? Explain in sentence form using your textbook as a reference.

For the figure illustrating the results of acetic acid concentration OR isopropanol concentration, answer the following (in sentence form, using your textbook as a reference):

- Compare your results to your hypothesis for the experiment. Are your results as expected? Explain.
- Based on the class results, what acid concentration(s)/isopropanol concentration(s) were the most damaging to the beet cell membranes? Explain in sentence form using a reference.
- Based on the class results, what acid concentration(s)/isopropanol concentration(s) had little or no effect on the beet cell membranes? Explain in sentence form using a reference.

Thought Questions.

1. What would happen if animal cells were placed in a solution of pure water? Use the terms osmosis, hypertonic and hypotonic in your answer. Would the same be true of plant cells placed in pure water? Why or why not?
2. Typically, an instrument known as a spectrophotometer would be used to measure color intensity. What is a spectrophotometer? What is the advantage of using a spectrophotometer rather than your eyesight to measure color intensity?
3. In 1925, Gorter and Grendel obtained lipid from cell membranes by bursting and removing the contents of red blood cells. They spread the lipid in a layer one molecule thick on the surface of a tray of water. The area covered by this lipid layer was twice as large as the surface area they had calculated for the original cells. Can you explain the discrepancy?

Cited References

Reece, J.B. L.A. Urry, M.L. Cain, S.A. Wasserman, P.V Minorsky and R.B. Jackson. 2011. Campbell Biology, Ninth Edition. Pearson Benjamin Cummings, San Francisco, CA.

Materials

Materials required for the Membrane Stress Laboratory are detailed in the student outline section of this document. Most materials required are household items (*e.g.* cutting boards, knives, vinegar and rubbing alcohol), however, students and instructors will need access to some lab consumables (*e.g.* 15 mL Falcon tubes and serological pipettes) and a color printed version of the colorimetric chart to interpret the betacyanin absorbance values and concentrations (printable handout is in Appendix A). Access to a computer with internet connection and video software (such as Zoom®) are important supports for students in the event of confusion or technical difficulty with carrying out the experiments. A spreadsheet software with basic graphic capabilities (*e.g.* Microsoft Excel®) is also useful for recording and interpreting results but not strictly required. The described activity can be scaled up or down with the number of students in the course, so long as the needed lab consumables and technical resources permit (easily up to 500 or more students).

Notes for the Instructor

The focus of our implementation of take-home laboratory kits was to provide our students with some level of experiential learning and development of basic laboratory experimental practices and scientific method. As described above, we needed to ensure that all of the activities could be safely performed from home, did not involve the use of exotic or dangerous materials and science equipment and ultimately, did not place students in any danger beyond that of typical food preparation. Thus, we converged on the described membrane stress activity, along with our four additional take-home labs, that were easily adapted from our usual teaching lab activities.

Without access to a spectrophotometer for quantification of the amount of betacyanin released from beet cells (an indirect indicator of membrane disruption), we developed a colorimetric comparison card that shows the absorbance values given by our basic spectrophotometers at A460 nm for various color tones of betacyanin solutions (see Appendix A).

We found that the apparent “color” of the solution to the eye is not simply different shades/intensities of fuchsia/pink and we had to adjust the color profile of the colorimetric card (*e.g.* add more purple) as the intensity/absorbance reached 1 absorbance unit. Also, we found that the level of lighting and spectrum of light in the location where solutions are being compared to the colorimetric card can result in small changes to the interpreted absorbance values. However, we found that the measurements taken by students were remarkably consistent and produced a reliable class data set for subsequent analysis and lab reports.

The biggest contributing factor in producing consistent results across students came in preparing the beet samples for the experiment. We found that it is very important that students are careful to make each of the beet pieces as close to the same size as possible. In the kits we also included a laminated paper ruler to help students to cut the beet pieces exactly as specified. Careful use of a sharp knife was a key to success in this aspect. Dull knives produced rougher and more inconsistent cuts.

We could not examine this specifically, but we also speculated that some of the variance in the results in the class data sets were due to the properties of the particular beets that students used for the experiment. For instance, older, softer beets may have released more or less betacyanin than those of fresher, more turgid beets. Thus, we recommend that students attempt to use the freshest produce available to them for more consistent results. During the live ViABLE presentation, we also found that different types of beets available in various parts of the world, may have different pigment profiles. In this case, using a modified color card that is calibrated to the regional varieties of beets may be required for students to accurately interpret their results.

Results and Discussion

Membrane Stress: Laboratory Results

The take-home membrane stress experiment described above was implemented for both the Fall 2020 and Spring 2021 terms. Students were required to participate in both pre-lab and post-lab activities. The pre-lab components consisted of attending a synchronous pre-lab lecture during the first week of the lab and submitting a pre-lab assignment targeted at developing their competence with the scientific process. The students then conducted their experiment during the second week and submitted their experiment data to Microsoft Excel for the web before using the compiled lab section data to complete their post-lab assignment.

The figures below display the aggregate experimental data for all eight lab sections from Spring 2021 for the temperature, acetic acid, and isopropanol treatment of beet pieces (Figures 1-3). While student data from the individual lab sections varied somewhat, the overall treatment trends across all sections were consistent as a whole (data not shown).

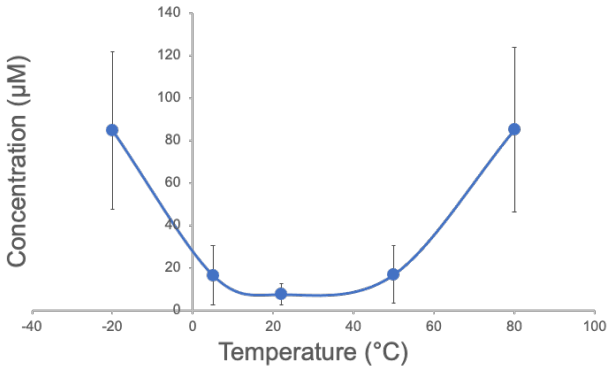

Figure 1. The effect of temperature on the concentration of betacyanin released from *Beta vulgaris* cells. Values are means ± standard deviation, n = 191.

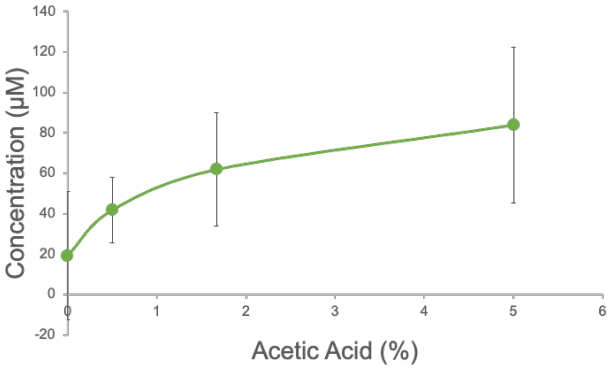

Figure 2. The effect of acetic acid on the concentration of betacyanin released from *Beta vulgaris* cells. Values are means ± standard deviation, n = 95.

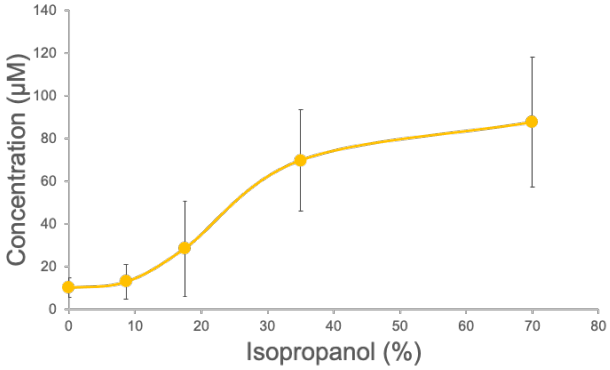

Figure 3. The effect of isopropanol on the concentration of betacyanin released from *Beta vulgaris* cells. Values are means ± standard deviation, n = 93.

Interestingly, the means and standard deviations for treatments with the highest measured betacyanin concentrations were remarkably similar for all of the experimental trials (~80 µM +/- 40 µM). In all cases there was a clear concentration-dependency for increased betacyanin in response to increasing isopropanol and acetic acid concentration (Figures 2 and 3) and the greatest concentrations of betacyanin were observed at temperatures below freezing (-20°C) and those well above physiological temperatures (80°C) (Figure 1).

Generally, the greatest variability in observed betacyanin concentration came from treatments that are expected to show the greatest amount of cell membrane damage (*e.g.* Figure 1, -20°C and 80°C treatments; and Figure 2, 35% and 70% isopropanol). It is possible that this observation can be attributed to individual beet samples that may contain significantly different total amounts of betacyanin and this effect is

only observed under conditions that promote very extensive cell membrane disruption.

Due to the large amount of variation observed for individual student data, the use of averaged lab section consensus data was essential to clearly illustrate the temperature- and concentration-dependent trends from each experiment (Figures 1-3). The variation observed in the three experimental treatments is likely from a variety of factors that include: (1) insulation properties of containers used by individual students for the temperature treatment; (2) inconsistencies in the original concentration and the serial dilution of solutes for the acetic acid and isopropanol treatments; and (3) differences in sample handling such as inconsistent mixing of solutions between treatments.

We were interested to compare the student results from the take-home beet membrane laboratory trials with student results from our typical in-laboratory activities. While the temperature treatments used in the take-home kit were modified with respect to the in-lab activity, the overall trend and magnitude of the temperature-response treatment were remarkably consistent (Figure 4). The isopropanol and acetic acid treatments are not typically part of the in-lab exercises so we could not compare differences between take-home and in-lab results for these trials.

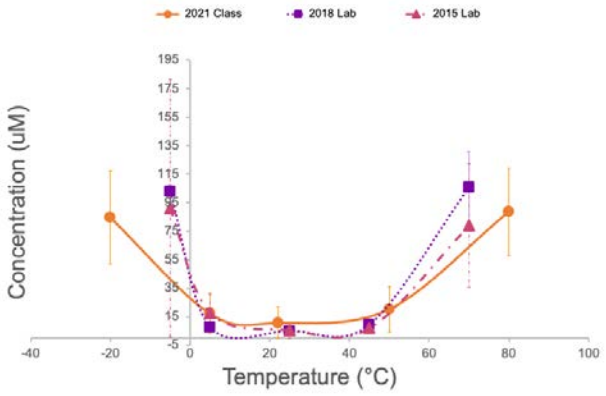

Figure 4. Temperature data from individual labs in 2015 and 2018 (n = 40) compared to the all-lab consensus data from 2021 (n = 191). Values are means ± standard deviation.

It is important to note that the in-person and take-home version of this experiment have slightly different procedures. First, students test the effect of temperature and SDS in-person rather than temperature, isopropanol, and acetic acid. Second, for the temperature component, in-person students test a narrower range of values (-5 to 70°C) compared to the take-home experiment (-20 to 80°C). Finally, when offered in-person, students use a Spectrophotometer rather than pre-calibrated absorbance cards to measure betacyanin absorbance. Regardless of these discrepancies, the take-home version of this laboratory still highlights the same concepts as the in-person offering and allows us to address the learning objectives associated this experiment, even in a remote setting.

Remote Laboratory Kit Effectiveness

Following completion of Biology 1010, students from the Fall 2020 and Spring 2021 terms were asked to complete a survey to gather data about their experiences with the take-home laboratory kits and online learning. These surveys were set up using the Qualtrics® survey platform and run separate from our standard term-end course evaluations. Students were asked six questions related to which labs they enjoyed or disliked, how they felt the experiments addressed the learning objectives of the course and their views on the effectiveness of the take-home laboratory kits. The aggregate student responses from this survey are detailed in Figures 5 – 7.

In both Fall 2020 and Spring 2021 terms, students seemed to prefer the earlier, less technically complex labs, such as Cell Membranes and DNA Structure and Function (Figure 5), while disliking the longer, more difficult labs conducted towards the end of the term, such as Enzymes and Respiration (Figure 6). The experiments conducted later in the term combined skills students built throughout their previous work and are therefore more intensive than earlier experiments, both in the procedures that student are expected to follow along with the associated assignments.

The following quotes obtained from the survey help elucidate why we might be observing these trends:

“My favorite was the respiration lab because it involved a lot of setting up and careful watching. I truly felt like I was doing an exciting lab! I enjoyed all labs, but my least favorite was the enzymes experiment because it was fairly hard to keep up with how rapid the samples were accumulating oxygen.”

“I think food microbiology was my favorite. The only one I didn't really like was enzymes and that was only because of how long it took. If I were in a lab, it wouldn't have been that bad - it is a good time to talk to TA's and instructors during those labs, and I think that is what I am missing the most.”

These statements indicate that perhaps it was a combination of lab difficulty and the isolated at-home environment that attributed to the dislike of labs such as Respiration and Enzymes. Further work will be required to find the optimal balance between building up students' skills to complete these more complex experiments, and perceived difficulty as well as workload, especially if faced with another online term in the future.

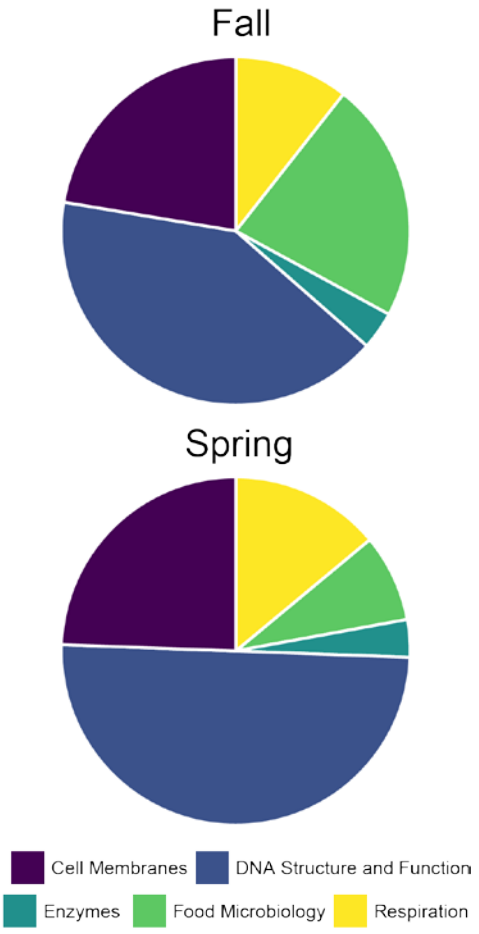

Figure 5. Student responses to the question "Which was your favourite lab activity from the take home kit?" from the Fall 2020 (n = 87) and Spring 2021 (n = 86) terms.

In addition to liked and disliked labs, students were asked specific questions about the success of the term, the online resources provided (including the lab manual, online instruction videos, synchronous and asynchronous instructor assistance) and the take-home laboratory kits.

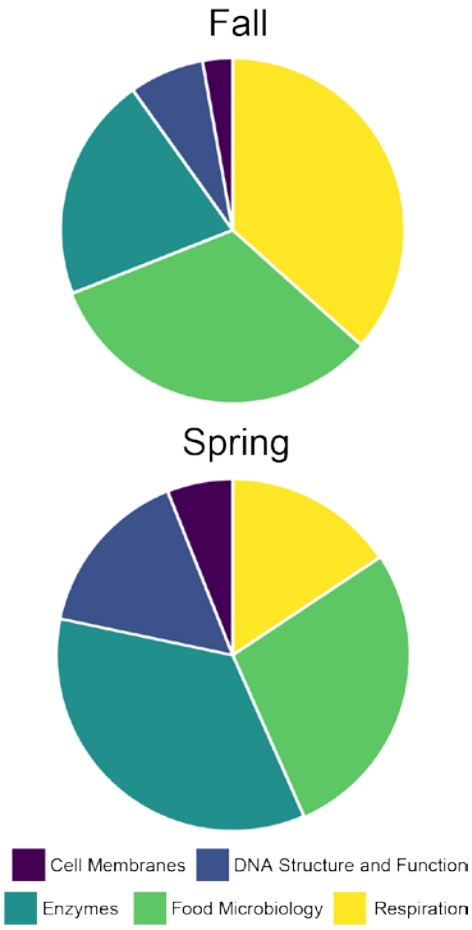

Figure 6. Student responses to the question "Which was your least favourite lab activity from the take home kit?" from the Fall 2020 (n = 74) and Spring 2021 (n = 83) terms.

Overall, students seemed quite satisfied with the quality of the laboratory experience and supporting materials, with most students selecting a score of 4 out of 5 for each question.

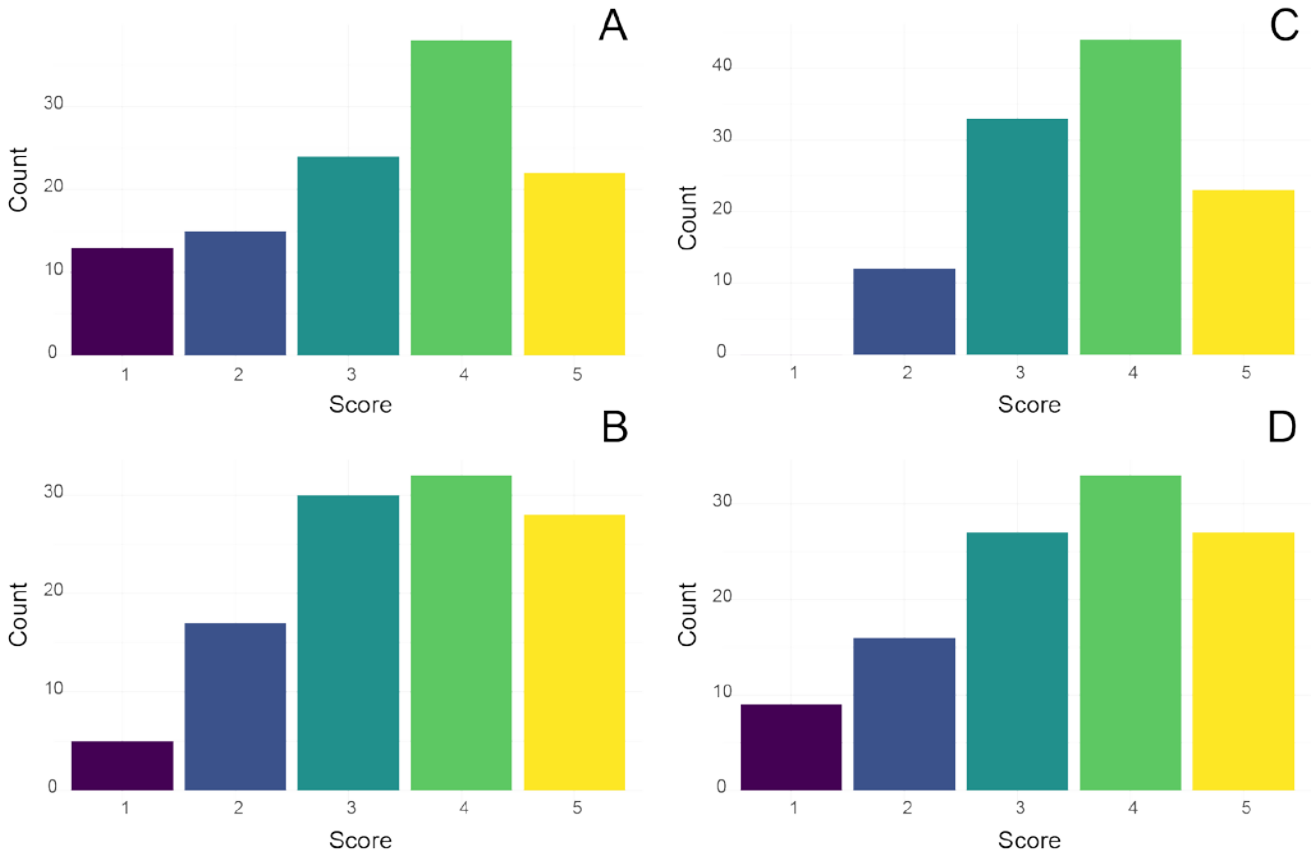

Figure 7. Student responses to the questions: (A) "How well did the activities enhance and reinforce the main concepts of biological molecules, structure and function?" with 1 corresponding to 'not at all' and 5 corresponding to 'extremely well'. Mean response 3.37 ± 1.27, n = 112. (B) "Were the activities easy to follow without significant technical difficulties?" with 1 corresponding to 'very difficult' and 5 corresponding to 'very straight forward'. Mean response 3.54 ± 1.15, n = 112. (C) "Rate the scientific quality and rigor of the activities." with 1 corresponding to 'very poor' and 5 corresponding to 'excellent rigor and quality. Mean response 3.70 ± 0.92, n = 112. (D) "How helpful were the lab manual, online instruction videos and instructor assistance in completing your lab activities?" with 1 corresponding to 'not helpful' and 5 corresponding to 'extremely helpful'. Mean response 3.47 ± 1.23, n = 112.

The following quotes in response to the question "Given the risks involved with COVID-19, would you have preferred to have an in-person laboratory as opposed to the take-home lab kits this past semester?" highlight student opinion of the take-home laboratory kits:

"Yes and no. I do think my experience would have been much better in-person because there would be a supervisor and other individuals to help me physically with the experiments. However, it was a fantastic way to get the same skills and knowledge as I would have in-person, while still keeping myself and others safe!"

"It would have been ideal to have an in-person lab, but due to [COVID]-19 I preferred the online labs and take-home lab kits. They were easy to follow and thorough and covered the content we needed to quite well."

"Given the risks involved with [COVID]-19, I prefer the take-home lab kits over in-person laboratory because although it would've been excellent working in the lab, given the circumstances the take-home lab kit did just of an effective job enhancing concepts in Biology 1010."

Conclusions

In sum, we conclude that the set of labs/resources used were an adequate and helpful substitute for in-person lab exercises and aided students in developing knowledge of the scientific process, topics in cell biology, and allowed them a hands-on component of the online course that enabled them to stay engaged. While students show a clear preference for in-laboratory teaching labs, we found that the take-home laboratory data gathered was qualitatively comparable to student data gathered from the equivalent in-person laboratories and supported the underlying biological principles taught in the Biology 1010 lecture. Given the physical distancing constraints during the COVID-19 pandemic, it is our opinion that our take-home laboratory kits were a suitable and effective substitute in lieu of our in-laboratory activities. Now that we have developed the set of five take-home laboratories, we feel much more prepared to deliver the Biology 1010 course to our students in the event of future pandemic-related university shut-downs. The suite of activities could also be adapted to delivering introductory cell biology course material for remote student learning and offer an experimental component to complement course materials. We encourage any individuals that wish to know more about our take-home laboratories to contact us for additional details.

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We thank all of the Biology 1010 students that participated in our take-home laboratories this past year and their valuable feedback on their experiences. We also thank the graduate students that assisted with the assembly of the lab kits and the various colleagues at our institution that assisted with the distribution of the kits to students and evaluation of the safety of the activities.

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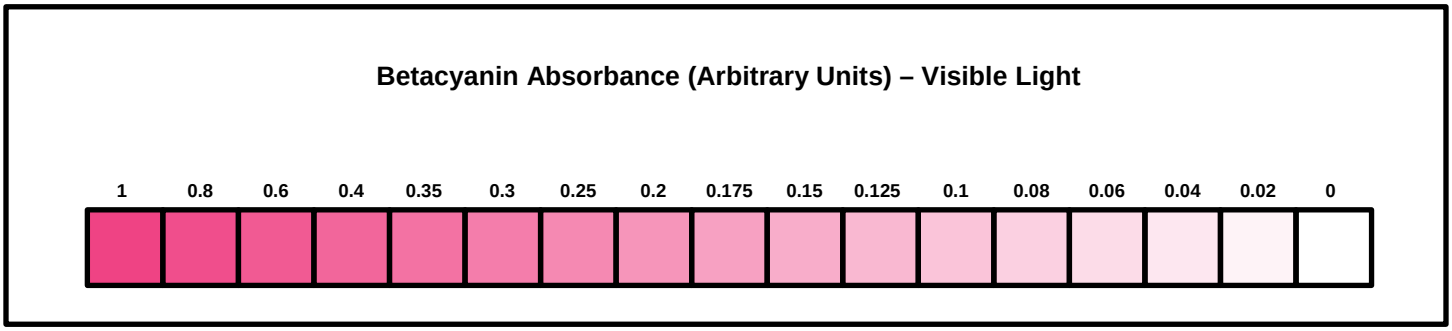
Appendix A

Printable Colorimetric Comparison Card for Evaluating Betacyanin Absorbance without a Spectrophotometer



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