ONLINE INQUIRY & INVESTIGATION

Assessing Inquiry Process Skills in the Lab

Using a Fast, Simple, Inexpensive Fermentation Model System

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Incorporating inquiry-based learning in the college-level introductory biology laboratory is challenging because our labs serve the dual purpose of providing a hands-on opportunity to explore content while also emphasizing the development of scientific process skills. Time limitations and variations in student preparedness for college further constrain our ability to offer a discovery-based, student-centered lab experience. At West Chester University, the Introductory Biology course serves both majors and non-majors and has a large enrollment (300/year) with multiple laboratory sections and a steady stream of new instructors. We have learned to balance our goals to teach content while engaging students in the inquiry process through activities called "inquiry-based challenges." Challenges are performance-based laboratory assessments that allow students to demonstrate problem-solving skills when presented with a problem in context. Here we describe a rapid, inexpensive modification of a traditional fermentation lab that should improve the ability of teachers to incorporate this lab within a limited time frame. More importantly, we introduce a template for inquiry-based challenge activities that can be modified and used to assess problem solving, experimental design, and data analysis abilities of students at many levels.

The yeast fermentation lab is typically used in both high school and college level introductory courses to teach about substrates, products, enzymes, and metabolic pathways. There are numerous variables that can be tested in this model such as the role of pH, temperature, substrate type and concentration, detergents, and metabolic inhibitors (Tatina, 1989; Reinking et al., 1994; Leonard, 2003; Collins & Bell, 2004). The experimental setup is simple and can be performed at a variety of levels without major expense. One limitation to the procedure, however, is the time required for the experiment when large volumes are used. Typically the experiments take up to one hour to complete and students are often spending that time waiting to collect results (Collins & Bell, 2004).

We have developed a yeast fermentation experiment using capillary tubes that minimizes time and increases student participation in the experiment. Numerous variables can be tested yet the time required to set up and test any variable is reduced from hours to minutes using this approach. The major advantage of this rapid method is that it allows time for students to complete and discuss the results of a planned experiment, followed by a performance-based assessment using inquiry process skills. The "inquiry-based challenge" assessments allow students to work cooperatively to solve the problem.

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Materials

- baker's yeast
- balance (for making solutions and weighing yeast)
- disposable tubes
- Sharpie® markers
- rulers
- 100 mm capillary tubes open at both ends (hematocrit tubes)
- Critoseal (for plugging capillary tubes)
- stop watches
- buffer (0.02 M K_2PO_4, pH 5.0)
- various substrates (0.1 M of glucose, sucrose, lactose, fructose, galactose)
- various inhibitors (1% sodium bisulfite, high temperature)
- substrates (glucose, sucrose, fructose) with 6% NaCl added for challenge

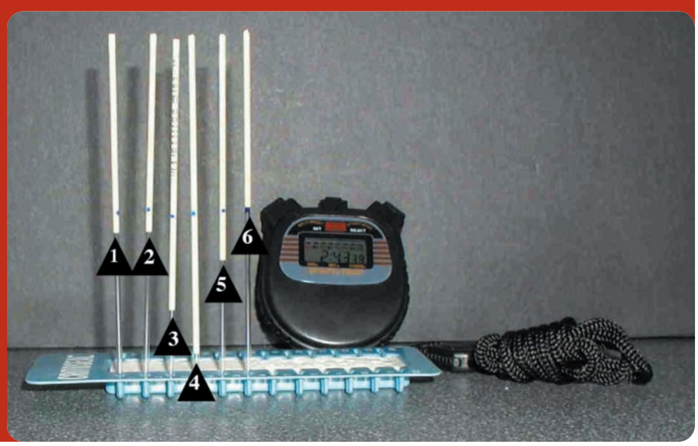
Procedure

1. Fill a plastic disposable tube with 0.3 grams of baker's yeast, add 10 drops of buffer, and mix for three minutes until the mixture becomes a thick slurry.
2. Add 10 drops of the assigned carbohydrate solution or water to the tube and mix for an additional two minutes.
3. Using a capillary tube open at both ends (1.5-1.8 x 100 mm), mark the capillary tube with a Sharpie® marker at the midpoint of the tube. Fill the tube with yeast mixture to the midpoint mark by placing the capillary tube into the test tube and holding both tubes so that they are nearly horizontal. Be careful to prevent air from entering the capillary tube, as it should be a continuous column of the yeast solution.
4. After filling, the open end of the half- filled capillary tube should be closed with your index finger to prevent loss of solution. The solution end of the capillary tube is inserted into the critoseal and gently pushed to the bottom of the container with a slight twisting motion. The sealed tube is then placed in one of the numbered receptacles on either end of tray with the open end downwards and the critoseal end up (see Figure 1a).
5. The mark on the tube will be your 0 mm mark at T = 0. Measure the distance that the fluid level moves downward every two minutes until the solution gets to the end of the capillary tube. An example of a typical experiment demonstrating variation of fluid levels when yeast are fermenting different substrates is shown in Figure 1b.
6. If your solution does not move within 12 minutes, stop your reaction.

Upon completion of the experiment, every student prepares a graph of his/her results and calculates the fermentation rate (mm/min) for each condition. Class results are tabulated on the board so that students can easily see the variability of results between groups and statistical

Figure 1a.
Six capillary tubes filled with yeast and various substrate solutions at T = 0. Notice that the fluid level for all of the capillary tubes is at the midpoint of each tube.

Figure 1b.
Every two minutes, gas production can be determined by measuring the distance between the midpoint marker and solution interface. Each tube contains yeast plus a different substrate or water (Tube 1 = lactose, 2 = galactose, 3 = glucose, 4 = sucrose, 5 = fructose, 6 = water). Arrows indicate the new level of the solution interface for the control (Tube 6) and each tested substrate (1-5).



analysis is performed. Discussion questions such as "Which substrate resulted in the greatest fermentation rate by yeast?" will generate different answers depending on whether individual versus class results are considered. Thus, students learn to appreciate the importance of replication in experimental design to yield accurate conclusions.

This hands-on activity is useful for discussing the role of specific variables on metabolic processes, and introduces the students to a simple technique for measuring fermentation rates. Because the method is rapid, there is still time for students to apply the techniques they have learned to a new problem. With one hour remaining in the laboratory, the students are given an "inquiry-based challenge" assessment. The challenge consists of a short problem that requires the student team to use inquiry skills to solve the problem. These skills include:

- formulating a testable hypothesis
- designing and conducting a scientific investigation
- presenting results using tables or graphs
- reflecting on the original hypothesis (Doran et al., 2002).

The advantage of using challenge assessments rather than an open-ended inquiry approach is that we eliminate the time needed for students to choose variables to test and also streamline the lab preparation for large classes. An example of the responses from a student group to this fermentation challenge can be seen in Figure 2.

Sample Challenge

Fermentation in Seawater Challenge (5 points)

The Challenge

Organisms respond to environmental change in numerous ways. They may increase or decrease their rate of metabolism depending on the conditions. Some organisms can live in different environments, spending some of their time in freshwater and some in seawater. Adaptation to different environments may have an effect on cellular metabolism.

Salt (sodium chloride–6% NaCl) has been added to sugar solutions to simulate a seawater environment. Your challenge is to determine the effect of this environmental change on yeast fermentation.

1a) *What is your prediction?*
Do you think the salt will increase, decrease, or have no effect on yeast fermentation?
Why?

b) *State your hypothesis as a null hypothesis.* (1 point)

2. *What procedure will you use to test your hypothesis?* (1 point)

Figure 2.
Example of student work for fermentation inquiry-based challenge with instructor comments.

Fermentation in seawater

Introduction: Organisms respond to environmental change in numerous ways. They may increase or decrease their rate of metabolism depending on the conditions. Some organisms can live in different environments, spending some of their lives in freshwater and some in seawater. Adaptation to different environments may have an effect on cellular metabolism.

Salt (sodium chloride- 6% NaCl) has been added to sugar solutions (glucose, fructose, sucrose, ~~or maltose)~~ to simulate a seawater environment. Your challenge is to use the sugar solution listed below to determine the effect of this environmental change on yeast fermentation.

Sugar + NaCl tested = GLUCOSE + NaCl

WHAT IS YOUR PREDICTION? Do you think the salt will increase, decrease, or have no effect on yeast fermentation? Why? (1 point)

The NaCl will decrease the yeast fermentation the ionic NaCl compound will alter the active site, making it more difficult for fermentation to occur.

Great idea!

State your hypothesis as a null hypothesis:

The salt in the glucose solution will have no effect on yeast fermentation.

WHAT PROCEDURE WILL YOU USE TO TEST YOUR HYPOTHESIS (1 point)?

To test the hypothesis, we will fill a disposable tube to the etch mark with yeast. We will add 5 drops buffer and mix this for 3 minutes. Then we will add 10 drops of glucose + NaCl and mix for 2 more minutes. We will fill a capillary tube with the mixture, plug the end with critoseal, and place it under a heat lamp. We will mark the original placement of the mixture, and measure the change after 12 minutes. The same procedure will be done with plain glucose for the control.

Good

WHAT ARE YOUR RESULTS (1 point)?

Time (min)	Glucose + NaCl	Glucose
0	0 mm	0 mm
2	0 mm	1 mm
4	0 mm	4 mm
6	1 mm	10 mm
8	3 mm	15 mm
10	7 mm	23 mm
12	12 mm	33 mm

WHAT CONCLUSIONS CAN YOU DRAW FROM YOUR RESULTS? (1 point)

The conclusion we draw is that NaCl slightly inhibits the fermentation of yeast. The control with glucose alone fermented very quickly, and formed a lot of gas. The one with NaCl took longer to begin, but still fermented quite a bit.

Great Job!

WAS YOUR PREDICTION CORRECT? Why or why not? (1 point)

The prediction was correct, because according to our results, fermentation was slightly decreased compared to the control. This might be an insignificant difference, but we would have to do many experiments to determine that.

Good

3. *What are your results?* (1 point)
4. *What conclusions can you draw from your results?* (1 point)
5. *Was your hypothesis correct? Why or why not?* (1 point)

The student performance on this challenge activity over the past two years has averaged 85% and has been incorporated in over 25 laboratory sections by 10 different laboratory instructors. Student performance is better on these types of assessments as compared to traditional quizzes because students can interact and share their problem-solving strategies with each other and with the instructor. As we have gained experience with this assessment tool, we have gradually increased its contribution from 10% to 30% of the total lab grade.

At the end of the semester, all of the students in the course are asked to provide feedback on their lab experience. In addition to the fermentation lab, we embed numerous other challenge activities in different labs throughout the semester. Rather than ask the students directly if they thought the challenges helped them to develop inquiry process skills or understand content, we designed a self-assessment in which students write three to five sentences in response to several questions. One of the questions reads as follows:

> *Lab experiences should help you to learn the processes that scientists use to explore problems. Choose one activity performed in lab where you had an opportunity to design an experiment. Explain your answer.*

95% of the students refer to a specific challenge activity (or challenges in general) as an opportunity to design an experiment. Another question asks:

> *Some lab experiments require data collection and analysis. Choose an experiment where you successfully collected data and felt confident drawing conclusions from the data. Explain your answer.*

For this question, 40% of students refer to a challenge activity although the majority of students identify a multiweek insect growth experiment as the one where they successfully gathered and analyzed data. Based on these results, we are confident that inquiry-based challenges are a highly effective way to help students learn the experimental design component of the inquiry process. Challenges also enhance students' perception of their ability to collect and analyze data.

The advantage of this type of assessment over the traditional multiple choice lab quizzes or lab practicals is that it allows students to generate a product rather than select responses to questions. It also addresses the *National Science Education Standards* (1996) by emphasizing the importance of assessing student understanding and reasoning rather than discrete scientific knowledge using tests that only measure low level cognitive skills. All students, regardless of background and high school preparation, are able to successfully complete these challenge activities. We believe that this type of laboratory performance-based assessment can be adapted to many levels and serve as another tool in our efforts to encourage students to develop their problem-solving skills.

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