Teacher Preparation Notes for
Alcoholic Fermentation in Yeast – A Bioengineering Design Challenge

This multi-part minds-on, hands-on activity helps students to understand both alcoholic fermentation and the engineering design process. In the first two parts of this activity, students learn about alcoholic fermentation and test for alcoholic fermentation by assessing CO₂ production by live yeast cells in sugar water vs. two controls. The third part of this activity presents the bioengineering design challenge where students work to find the optimum sucrose concentration and temperature to maximize rapid CO₂ production. Structured questions guide the students through the basic engineering steps of applying the relevant scientific background to the design problem, developing and systematically testing proposed design solutions, and then using initial results to develop and test improved design solutions.

Learning Goals
In accord with the Next Generation Science Standards, this activity:

- helps students to learn the Disciplinary Core Ideas:
  - LS2.B, "Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes."
  - LS1.A, "proteins… carry out most of the work of cells" (with regard to protein enzymes)
- engages students in recommended Scientific and Engineering Practices, including:
  - constructing explanations and designing solutions
  - planning and carrying out investigations
  - analyzing and interpreting data.
- helps students to understand the Crosscutting Concept, "Energy and matter: Flows, cycles and conservation"
- helps students to understand the Nature of Science principles that:
  - "Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings."
  - "Science knowledge is based on empirical evidence."
- helps students to prepare for Performance Expectation HS-LS2-3, "Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions."

Specific Learning Goals
- In alcoholic fermentation, a cell produces ATP using energy from reactions that require glucose, but do not require oxygen. The breakdown of glucose produces alcohol and CO₂.
- The chemical reactions in alcoholic fermentation are catalyzed by enzymes. As is typical of enzyme reactions, these reactions can be speeded up by increasing the concentration of substrate and/or by increasing temperature to an optimum level; both of these changes increase the rate at which substrate molecules collide with the active sites of the enzymes. Increases in temperature above the optimum result in changed shape of the active site which slows the rate of reaction.
- To meet an engineering design challenge, you should specify the design criteria, use relevant scientific information to propose design solutions, systematically test proposed design solutions, and use the results of initial testing to propose improved design solutions for further testing.

1 By Dr. Ingrid Waldron and Dr. Jennifer Doherty, Department of Biology, University of Pennsylvania, 2016. These Teacher Preparation Notes and the related Student Handout are available at http://serendipstudio.org/sci_edu/waldron/#fermentation
2 Quotations are from http://www.nextgenscience.org/sites/default/files/HS%20LS%20topics%20combined%206.13.13.pdf
Equipment and Supplies

II. Testing for Alcoholic Fermentation in Yeast Cells

Equipment\(^3\) (number needed for each group of four students in your largest class)

- Graduated cylinder to measure 80 mL (1)
- Ruler to measure millimeters (3)
- Timer or some other way of keeping track of minutes and seconds (1)
- Scale, accurate to 0.1 g (preferably at least one for each two or three student groups)\(^4\)
- Thermometer for the range of 20-60°C (should be some way to prop this in the dishpan for the duration of the experiment or should be rapid response cooking thermometer) (1)
- Dishpan or other container that can be used as a warm water bath for the cups (1)
- Marker or other method for labeling cups (1)

Supplies (amount needed for each group of four students)

- 10 oz. clear plastic cups (or another clear, relatively narrow and tall container of similar size with thin walls that readily conduct heat) (3)\(^5\)
- Plastic spoons for stirring (6)
- 8 g of yeast (fast-rising highly active baker’s yeast or breadmaker yeast; make sure that the yeast has not reached its expiration date.) +80 mL of suspension of dead yeast cells (4 g of yeast in 80 mL of water; boil for 5 minutes to kill the yeast cells; before distributing 80 mL to each student group, adjust temperature to ~35°C and be sure to stir the suspension thoroughly)

In total, you will need 12 g of yeast per student group; each triple package of yeast has 21 g.

- 1.5 g of sucrose
- Warm water (~35°C; the water needs to be warm to ensure that the yeast metabolism will be rapid enough to produce good results in the 10 minute observation period)

We recommend that you use the instructions on page 3 of the Student Handout to prepare several cups of living yeast in sugar water either before or near the beginning of the laboratory period, allow 10 minutes for alcoholic fermentation and pass these cups around so students can see what the layer of foam produced by the CO\(_2\) bubbles looks like.

III. Bioengineering Design Challenge

- The same equipment and supplies as for part I, but you will need 24 g of live yeast per student group (no dead yeast needed) and the quantity of sucrose needed will vary, depending on students’ proposed design solutions and the resulting Class Investigation Plans for testing the proposed design solutions.
- Some way to vary the temperature of the water in the cups and bath

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\(^3\) If you do not have enough time for the bioengineering design challenge in part III, you may want to streamline the procedure on page 3 of the Student Handout by omitting the warm water bath (which is needed to equalize the temperature in different cups in Part III). Also, if you are omitting the bioengineering challenge and you don't have thermometers, students can just use water and killed yeast solution that is warm to the touch. Since timing is not so crucial for Part I, the students do not need to time seconds and you can use just one ruler per student group to measure the depth of the foam layer. If you use this approach, we recommend that you have three students in each student group. Your students can use the streamlined procedures for Part II shown in the substitute page 3 for the Student Handout provided on the last page of these Teacher Preparation Notes.

\(^4\) Scales are desirable since it is easier to accurately measure 4 g of yeast and 0.5 g of sucrose, but if you do not have scales, you can substitute 1.5 teaspoons of yeast (4.3 g) and 1/8 teaspoon of sucrose (0.5 g) in the instructions on page 3 of the Student Handout and purchase readily available cooking measuring spoon sets. You will also want to supply something like plastic knives, so students can use the back of a knife to level off each volume measure.

\(^5\) For the cups used in pilot testing, we found that the foam layer produced by 100 mL of water with 5 g of yeast tended to overflow the cups, which is why is we recommend using 80 mL of water with 4 g of yeast.
**Instructional Suggestions and Background Information**

If your students are not familiar with ATP, we recommend that you precede this alcoholic fermentation activity with our analysis and discussion activity "How do biological organisms use energy?" (available at [http://serendipstudio.org/exchange/bioactivities/energy](http://serendipstudio.org/exchange/bioactivities/energy)).

You may want to complete the questions on pages 1-2 of the Student Handout on the day before the lab period for the experiment. This should ensure that your students will have enough time to complete the experiment (page 3 of the Student Handout) and the interpretation of results (page 4) during a 50-minute lab period.

The Bioengineering Design Challenge will probably require at least two 50-minute class periods. This is in line with previous research which indicates that significant class time is required for students to develop a meaningful understanding of the engineering process.

If you do not have enough time for the bioengineering design challenge and plan to just use part I, Introduction, and part II, Testing for Alcoholic Fermentation in Yeast Cells, we recommend that you simplify the procedures on page 3 in accord with the suggestions in footnote 2 on page 2 and the proposed simplified substitute for page 3 of the Student Handout which is available on the last page of these Teacher Preparation Notes.

In the Student Handout, numbers in bold indicate questions for the students to answer and Ø indicates a step in the experimental procedure for the students to do.

The PDF of the Student Handout shows the correct format; please check this if you use the Word document to make revisions.

A key is available upon request to Ingrid Waldron ([iwaldron@sas.upenn.edu](mailto:iwaldron@sas.upenn.edu)). The following paragraphs provide instructional suggestions and additional background information, some for inclusion in your class discussions and some for your understanding and/or responding to student questions.

**I. Introduction**

Yeast are single cell fungi which absorb nutrients from their environment (e.g. bread dough, grapes, tree bark). The yeast which is used to make bread is *Saccharomyces cerevisiae*. As the bread bakes, the ethanol produced by alcoholic fermentation evaporates. Bubbles which contained carbon dioxide provide the fluffy texture of bread. *S. cerevisiae* and other members of the same genus are used to make wine and beer where, obviously, the production of alcohol is the major goal. It is estimated that there are more than 50 billion yeast cells in 1 g of dry yeast. It may be surprising to your students that these little brown grains of yeast are alive.

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6 If you want to provide your students with additional background for understanding energy metabolism, including cellular respiration and photosynthesis, please see "Cellular Respiration and Photosynthesis – Important Concepts, Common Misconceptions and Learning Activities", available at [http://serendipstudio.org/exchange/bioactivities/cellrespiration](http://serendipstudio.org/exchange/bioactivities/cellrespiration).
This figure provides an overview of ATP structure, synthesis and utilization.

(Figure from Krogh, Biology – A Guide to the Natural World, Fifth Edition)

In fermentation a cell produces ATP using energy from reactions that require glucose, but do not require oxygen.

This activity focuses on alcoholic fermentation, the primary process used by *Saccharomyces cerevisiae* to produce ATP. This figure shows additional information about the process of alcoholic fermentation (also called alcohol fermentation). The last step in alcoholic fermentation restores NAD to its original form, which is needed so the fermentation process can continue.
Human muscles can use a different type of fermentation called **lactic acid fermentation**. Lactic acid fermentation is especially important during intense physical activity, when not enough oxygen is available to produce needed ATP by aerobic respiration.\(^7\)

Other types of fermentation are observed in various prokaryotes.

You may want to contrast alcoholic fermentation with **aerobic respiration** (also called cellular respiration) which uses oxygen as an electron acceptor. Both fermentation and aerobic respiration begin with glycolysis, but aerobic respiration includes the citric acid cycle and electron transport chain, so much more ATP is produced per glucose molecule.

Notice that aerobic respiration generates ~29 molecules of ATP for each glucose molecule; this number is less than previously believed (and still often erroneously stated in many textbooks). Brief explanations are provided in:

- "Approximate Yield of ATP from Glucose, Designed by Donald Nicholson" by Brand, 2003, Biochemistry and Molecular Biology Education 31:2-4 (available at [http://www.bambed.org](http://www.bambed.org)).

These recent findings are interesting as an example of how science progresses by a series of successively more accurate approximations to the truth.

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\(^7\) For further information about lactic acid fermentation during physical activity, see our analysis and discussion activity, "How do muscles get the energy they need for athletic activity?" ([http://serendipstudio.org/exchange/bioactivities/energyathlete](http://serendipstudio.org/exchange/bioactivities/energyathlete)).
Since anaerobic fermentation results in the production of much less ATP per glucose molecule than aerobic respiration, it may seem puzzling that *Saccharomyces cerevisiae* often use anaerobic fermentation even when oxygen is available. However, the production of ethanol which spills over into the environment appears to give *S. cerevisiae* a competitive advantage, since *S. cerevisiae* is more tolerant of ethanol than many other microorganisms. Also, *S. cerevisiae* is able to adopt a make-accumulate-consume ethanol strategy in which *S. cerevisiae* use alcoholic fermentation to rapidly metabolize glucose and produce ethanol during an initial growth phase and then switch to metabolizing ethanol when the glucose supply has been depleted. The oxidation of ethanol can supply energy for the production of additional ATP.

This figure shows evidence for the make-accumulate-consume ethanol strategy in a laboratory setting. The same phenomenon appears to occur in fruits in nature.

You may want to point out to your students that the ethanol which is added to gasoline is produced by alcoholic fermentation. (Background information is available at [http://en.wikipedia.org/wiki/Ethanol_fuel](http://en.wikipedia.org/wiki/Ethanol_fuel) and classroom activities are available at [https://www.glbrc.org/education/classroom-materials/cb2e-converting-cellulosic-biomass-ethanol](https://www.glbrc.org/education/classroom-materials/cb2e-converting-cellulosic-biomass-ethanol).)

Question 3 on page 1 of the Student Handout is designed for students who already have a basic understanding of enzymes and question 11 on page 5 is designed for students who understand the effects of substrate concentration and temperature on the rate of reaction. If your students are not already familiar with enzymes, you may want to precede this alcoholic fermentation activity with an introduction to enzymes (e.g. the activity, "Enzymes Help Us Digest Food", [http://serendipstudio.org/sci_edu/waldron/#enzymes](http://serendipstudio.org/sci_edu/waldron/#enzymes)) and/or you may want to introduce basic concepts during a class discussion of questions 3 and 11. For question 11 in the bioengineering design challenge, you may want to have your students mimic the activity of professional engineers who research the scientific literature for relevant information to assist their design process. Resources that may be helpful include:

- a helpful discussion of enzymes (available at [http://www.rsc.org/Education/Teachers/Resources/cfb/enzymes.htm](http://www.rsc.org/Education/Teachers/Resources/cfb/enzymes.htm)); this source can be useful for students who may have a basic understanding of enzymes but are having difficulty answering questions 3 and 11
- the figure shown on the next page which illustrates the concept of activation energy.
This figure can be used to reinforce student understanding that enzymes speed up reactions by reducing the activation energy required. As a result of the reduced activation energy, many more of the substrate molecules have enough kinetic energy to provide the needed activation energy to reach the transition state.

The figure below shows the enzymes that are needed for the last two steps in alcoholic fermentation. Notice how the product of the first reaction shown is the substrate for the next reaction. Ten additional enzymes are needed for the earlier steps in alcoholic fermentation (collectively called glycolysis).

II. Testing for Alcoholic Fermentation in Yeast Cells
If your students are not familiar with the effects of adding baking soda to vinegar, you may want to include a classroom demonstration of this reaction.

\[
\text{NaHCO}_3 + \text{HC}_2\text{H}_3\text{O}_2 \rightarrow \text{NaC}_2\text{H}_3\text{O}_2 + \text{H}_2\text{CO}_3 \rightarrow \text{NaC}_2\text{H}_3\text{O}_2 + \text{H}_2\text{O} + \text{CO}_2
\]

This demonstration may help your students understand why we cannot assume that bubbles produced by yeast in sugar water are produced by alcoholic fermentation. It should be acknowledged that we are still making assumptions in interpreting the results (e.g. that the bubbles produced are CO\textsubscript{2}).

In discussing question 5, you may want to relate the failure of dead yeast to produce CO\textsubscript{2} to the failure of bread to rise if an inexperienced baker prepares bread dough with very hot water (which can kill the yeast cells).

The instructions for the experimental procedure (on page 3 of the Student Handout) are more detailed and specific than would be needed for demonstrating that only the living yeast cells in sugar water produce CO\textsubscript{2}. However, these instructions will be very useful for students as they move into part II, the Bioengineering Design Challenge, which requires careful control of variables and quantitative assessment of the amount of CO\textsubscript{2} produced.\(^8\) To ensure that your students follow these rather detailed procedures, you may want to supplement the written

\(^8\) If your students will not be doing part II, you will probably want to use the simplified procedure shown on the last page of these Teacher Preparation Notes (and see also footnote 2).
instructions with a demonstration and/or have your students check off each step of the procedure as they complete it.

During the experiment, your students may notice a few bubbles on the surface of the cup with yeast in plain water; these are the aftereffects of stirring and not due to alcoholic fermentation, as indicated by the fact that the bubbles are present immediately after stirring and the amount of these bubbles does not increase over time. Careful observation of the cup with yeast in sugar water during the first few minutes reveals bubbles rising to the surface; these bubbles are coated with yeast suspension and generally do not pop, so this looks like bubbling lava.

We suggest that you post the following table for student groups to report the results of their experiments (see the bottom of page 3 in the Student Handout). This table will provide the information students need to answer question 9.

<table>
<thead>
<tr>
<th>Group ID</th>
<th>Depth of foam layer (mm):</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Living yeast in plain water (1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Living yeast in sugar water (2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dead yeast in sugar water (3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Starting temperature (°C)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ending temperature (°C)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The class discussion of questions 9b and 10 can help your students to develop better experimental procedure, which will be important for success in the Bioengineering Design Challenge of Part III.

**III. Bioengineering Design Challenge**

This Bioengineering Design Challenge includes several key features of engineering design:

- the need for clear criteria for a successful Design Solution
- the need to consider scientific principles and previous research results in planning your Design Solution
- the need to systematically test proposed Design Solutions
- the iterative nature of engineering practice with multiple rounds of first developing proposals and then testing them in order to develop the best Design Solutions.

Note that engineering design is not the same as trial-and-error "gadgeteering". The questions and class discussions presented on pages 5-10 of the Student Handout provide the scaffolding to guide your class through the steps of a relatively rigorous engineering design process. This extended approach is in accord with previous research which indicates that significant class time is required for students to develop a meaningful understanding of the engineering process.  

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9 It will be desirable for students to have additional engineering design experiences in the broader curriculum, including additional components of the engineering design process. Descriptions of a more complete engineering design process are available at [http://www.sedl.org/pubs are you/classroom-compass/cc_v2n3.pdf](http://www.sedl.org/pubs are you/classroom-compass/cc_v2n3.pdf) and [http://www.nap.edu/catalog.php?record_id=12635](http://www.nap.edu/catalog.php?record_id=12635) (especially the summary and chapter 5).
Scientific Background (page 5 of the Student Handout)
When the concentration of substrate increases, this increases the rate at which substrate molecules collide with the active sites of enzyme molecules and thus increases the rate of reaction. Once the concentration of substrate is high enough to saturate the active sites of the enzyme molecules, the reaction rate reaches a maximum and the curve of rate of reaction vs. substrate concentration plateaus. High sucrose levels (>2%, which would be 1.6 g of sucrose in 80 g of water) can result in decreased CO₂ production, due to osmotic stress on the yeast cells (http://www.classofoods.com/page2_2.html).

The rate of reaction reaches a maximum at an optimum temperature for each enzyme. Initially, as temperature increases, the rate of reaction tends to increase due to increased rate of motion of the substrate molecules, which results in more collisions of substrate molecules with enzyme active sites. Also, more of the substrate molecules have sufficient kinetic energy to provide the needed activation energy and the greater flexibility of the enzyme molecules facilitates induced fit. As temperature increases above the optimum level, the increase in vibrational energy of the atoms in the enzyme molecules puts strain on the bonds that are responsible for the secondary and tertiary structure of the enzyme molecules, so the active site changes shape and is less able to catalyze the reaction. With sufficient increases in temperature, the enzyme becomes denatured and no longer functions as a catalyst. ¹⁰

Proposing and Testing Your Design Solution (pages 5-9 in the Student Handout)
The overall sequence of this section is as follows:
• Students summarize the criteria for a good Design Solution and propose an initial Design Solution and experiments to evaluate their proposed Design Solution (questions 12-14).
• You lead a class discussion and develop a Class Investigation Plan to evaluate the proposed Design Solutions.
• Students carry out the experiments (using the basic procedure shown on page 6).
• You compile the data from question 15 for all the student groups and display the compiled data in the table from question 16.
• Students analyze these data to evaluate the effects of different amounts of sucrose and different temperatures (questions 17-20). Students propose a Design Solution based on these experimental results (question 21).

Student proposals for a Design Solution (question 13) should be based on the scientific background (question 11) and the criteria for a good Design Solution (question 12). Therefore, you may want to have a class discussion after students complete questions 11 and 12 and before they answer question 13.

Class discussion of question 14 will provide the opportunity to discuss the important methodological point that, you should evaluate the separate effects of each independent variable by testing different levels of each independent variable while holding the other independent variables constant. Many students are inclined to change several independent variables simultaneously which makes it impossible to identify the specific variable or variables responsible for any observed effects.

Class discussion of student answers to questions 13 and 14 can lead directly to a class discussion in which you develop a Class Investigation Plan for the first round of testing of your students' ¹⁰

¹⁰An additional effect of temperature has been observed for dry yeast. If dry yeast is suspended in cold water, cell membranes are initially leaky to small molecules; this results in a reduced rate of metabolism for the yeast cells. Complications due to this effect of initial temperature may be one reason for the variation in reported optimum temperatures for yeast activity (often given in the 40- 45°C range).
proposed Design Solutions. For this discussion, it will be very helpful to have the table from question 16 on the board or electronically displayed. This will help students to visualize that collectively they will test the amount of CO₂ production for three different sucrose amounts at each of three different temperatures. As you decide on the values for these variables, you can write the sucrose amounts in the first column of the table and the assigned temperatures in the top row. For practical reasons, we recommend that each student group test the three different sucrose amounts at a single temperature. Different student groups will test at the different temperatures. These tests will allow your class to evaluate the effects of sucrose concentration, the effects of temperature, and whether the effects of each independent variable are consistent at different levels of the other independent variable. We recommend that your students only test three sucrose concentrations at three temperatures, so you can have replicate tests for each condition in order to evaluate the consistency of results.

As you develop your Class Investigation Plan, you will have to make choices based on:

- the range of sucrose amounts and temperatures your students want to assess (Remember that this round of testing is meant to explore their initial hypotheses. In the Improving Your Design Solution section there will be a second round of testing where the results of this round of initial testing can be used to focus on a likely optimum range of sucrose amounts and temperatures.)
- the desirability of including the amount of sucrose and temperature used in part I to provide comparison data for a range where increased amount of sucrose and increased temperature are reliably associated with increased CO₂ production
- the desirability of having replication for greater reliability of results (This is particularly important since results with this method are not entirely consistent.)
- the number of student groups in your class (If you have fewer than 36 students, you will probably have to reduce the number of replicates.)

Students will need to be as careful as possible to follow exactly the procedures described in order to get relatively consistent and reliable results. It is important that all of the conditions except for the amount of sucrose be the same for different cups in the same student group; for example the water bath equalizes the temperature in the three cups for each student group. Students should distinguish between the depth of the foam layer and any coating of yeast suspension on the side of the cup. Even with careful experimental technique, results may be inconsistent and it may not be possible to identify exactly the optimum amount of sucrose or temperature. However, the results should be sufficiently accurate for students to observe increased CO₂ production with initial increases from 0.5 g of sucrose and a temperature of 35°C, followed by leveling off or decrease in CO₂ production with further increases in sucrose concentration and temperature (see explanations on page 9 of these Teacher Preparation Notes).

The graphs in questions 17 and 19 will be helpful for several reasons:

- These graphs can help students to evaluate the relationship between the rate of CO₂ production and different levels of the independent variables. Students may not have anticipated the nonlinear relationships of CO₂ production to sucrose concentration and temperature. (See page 9 of these Teacher Preparation Notes for background information for discussing questions 18d and 20d).
- These graphs will probably show variation in different replicates of the same conditions which will help students understand the importance of replication before drawing firm conclusions. In a class discussion of questions 18b and 20b, you could ask students if they are aware of any differences in methods that could have caused results that deviate
from general trends; this may help students realize the importance of precision in experimental methods to achieve accurate results.

- These graphs can help students to identify optimum Design Solutions (question 21).

**Improving Your Design Solution** (pages 9-10 in the Student Handout)

Students should use the results of their analyses in questions 17-21 to think about how to answer question 22a. In order to identify the optimum Design Solution, they may need to:

- extend the range of their investigations for either or both of the independent variables (amount of sucrose and temperature)
- get more detailed data within the range they have already investigated for either or both of the independent variables
- replicate results that were inconclusive due to inconsistent findings or limited data.

In the discussion of this question, you may want to point out that the need for repeated rounds of testing and experiments is typical of engineering design and scientific investigation generally. The results of each round of experiments provide the basis for planning the next round of experiments.

In this section, less scaffolding is provided on the assumption that students will use their experience thus far to take a more independent role in testing proposed Design Solutions.

You may want to assign question 26 as homework. In discussing this question, you may want to ask students to compare their final proposed Design Solution(s) with their initial proposal in question 13 and think about how any differences resulted from what they learned in the bioengineering design process. Also, you may want to mention the general principle in engineering design that there may be multiple possible satisfactory design solutions.

In the second part of the requested report, your students should consider how the yeast and sucrose may interact differently in bread dough vs. an experimental cup (see e.g. discussion of interactions of various bread ingredients with gluten at [http://busycooks.about.com/od/bakingscience/a/yeastbreadingredients.htm](http://busycooks.about.com/od/bakingscience/a/yeastbreadingredients.htm)). Also, testing with bread dough will allow evaluation of taste and texture. In contrast, testing in cups is faster and cheaper.

**Related Activities**

- "How do muscles get the energy they need for athletic activity?" ([http://serendipstudio.org/exchange/bioactivities/energyathlete](http://serendipstudio.org/exchange/bioactivities/energyathlete)) is an analysis and discussion activity in which students learn about the similarities and differences between aerobic cellular respiration and anaerobic fermentation, the conservation of energy and matter, and how these principles relate to athletic activity.
To test for alcoholic fermentation in yeast cells, in each student group:

- Experimenter 1 will test for CO₂ production by living yeast cells in plain water.
- Experimenter 2 will test for CO₂ production by living yeast cells in sugar water.
- Experimenter 3 will test for CO₂ production by dead yeast cells in sugar water.

Use the following procedure for your experiment:

<table>
<thead>
<tr>
<th>Experimenter 1</th>
<th>Experimenter 2</th>
<th>Experimenter 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Label your cups.</td>
<td>- Label your cup.</td>
<td>- Label your cup.</td>
</tr>
<tr>
<td>- Add 80 mL of water that is warm to your touch.</td>
<td>- Add 80 mL of warm killed yeast suspension.</td>
<td></td>
</tr>
<tr>
<td>- Tear a piece of scrap paper into quarters. Each of you should take a quarter-piece of paper for the next step.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Weigh 4 g of yeast and put this on your piece of paper.</td>
<td>- Weigh 4 g of yeast and 0.5 g of sucrose and put these on your piece of paper.</td>
<td>- Weigh 0.5 g of sucrose and put this on your piece of paper.</td>
</tr>
<tr>
<td>- Stir vigorously with a plastic spoon for one minute; smash any clumps of yeast and, if necessary, use your second spoon to scrape off any yeast that is stuck to the first spoon.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Make observations and record what you observe in the second and third columns of the table in question 7. Do not bump the cups!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- At the end of 10 minutes, measure the depth of the foam layer at the edge of the cup and record your results in the last column in the table in question 7. If the foam layer is not even, measure the depth at the thinnest and thickest points and record both measurements and the average.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Report the depth of the foam layer in each cup to your teacher.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Clean up.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notice that the proposed procedure is designed for groups with three students each, instead of four students. If you use this approach you will also need to modify question 7 in the Student Handout to omit temperature measurements.