Aerobic and Anaerobic Respiration

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INQUIRY COMPARED TO TRADITIONAL PEDAGOGICAL APPROACHES

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ABSTRACT: This article discusses and compares two approaches to teaching students about aerobic and anaerobic respiration. One approach was to have students take part in a common cookbook activity where a preset procedure is followed. In the second approach, students completed the same activity, but in a more inquiry-oriented fashion. Each approach was implemented in two 10^{th} grade classes. Students experiencing the inquiry approach were observed spending more time discussing the targeted concepts, and they performed better on the end-of-unit test. *This article addresses National Science Education Standards A, C, and G and Iowa Teaching Standards 1, 2, 3, 4, and 5.*

A major emphasis of the National Science Education Standards is the incorporation of inquiry-based instruction (National Research Council, 1996). Inquiry-based lessons are engaging when students describe objects and events, ask questions, construct explanations, test those explanations, and communicate their ideas to others (NRC, 1996). This form of instruction is often implemented using variations of a three phase learning cycle. First, during the exploratory phase, students explore phenomena through guided questioning and gain concrete experiences on which they can reflect during content discussion. Second, during concept development, students are introduced to the concept to be learned and asked to reflect and draw upon the concrete experience of the exploratory phase. Lastly, in the application phase, students are introduced to a new situation in which they can apply the understanding developed in the first two phases (Colburn and Clough, 1997). Contrary to traditional verification laboratory activities, instruction that incorporates the learning cycle places the concrete experience first. Students are more able to engage with concrete representations of concepts, and teachers are able to draw on these rich experiences during subsequent instruction. Inquiry places more demands on the teacher. For example, ambiguity often increases because students bring forward novel thinking and diverse prior knowledge that is often overlooked in traditional instruction. The extra effort is worth it as students are encouraged to more meaningfully engage with learning by making decisions and reflecting on common experience.

The Original Activity

The original activity (Figure 1) was a paper lab given to students and focused on what takes place within cells when human bodies go through aerobic and anaerobic respiration. The activity began with the teacher providing a thorough explanation of the lab and the reason why the lab was being conducted. Students were first told the concept they were to learn, and then followed a step-by-step procedure to apply the content knowledge they were already told. Students were told to construct a data table, discuss why there was variation between students, and to explain the amounts of carbon dioxide given off. The students were also expected to analyze the amount of ATP produced in aerobic vs. anaerobic respiration using equations given to them in advance.

While the activity described above may seem intuitively appealing, students are not encouraged to meaningfully engage with content. Students are not explicitly encouraged to think about the procedure being carried out and might carry out the procedure without considering the purpose or whether their results make sense. The concept is reduced to a set of abstract equations that are available to students before they have wrestled with the difficult process of making meaning out of the activity. This lack of meaningful engagement compelled us to make several important modifications to the original lab activity.

FIGURE 1

The original, unmodified classroom activity.

Aerobic vs. Anaerobic Respiration

In this laboratory exercise you will determine the relative amount of carbon dioxide you produce after various levels of activity. When carbon dioxide is dissolved in water it forms carbonic acid. The reaction is:

$$H_20 + CO_2 \quad H_2CO_3$$

By using an acid-base indicator you will determine the relative acidity produced by blowing carbon dioxide into water. The indicator, phenolphthalein, is pink in a basic solution with a pH of 8.4 or more. It is clear in a solution of pH less than 8.4. This color change allows you to monitor the relative amount of carbon dioxide in water. As CO_2 is added to water, the phenolphthalein will change from pink to clear. A base, NaOH, will then be added to return the phenolphthalein to pink. The more CO_2 that is added to the water, the more acidic the water will become. The more acidic the water becomes from added CO_2, the more NaOH that will be required to neutralize the acid and return the water to its original pH.

In addition to relative CO_2 production you will monitor your rate of breathing and your pulse. Your rate of breathing is controlled by respiratory centers in the brain. They are sensitive to concentrations of CO_2 in the blood. Recall that an increase in CO_2 lowers the pH. These receptors respond to a decrease in pH and cause an increase in the rate of breathing.

Materials:

Dropper of 1% phenolphthalein solution	Pipettes	100 mL graduated cylinder	Straws
Small bottles of 0.1M NaOH	250 mL Erlenmeyer flask	Distilled water	

Procedure:

A. Setting up a comparison flask
   Each table should set up a comparison flask of pink water to use as the standard color each time you begin and end an experiment. This will assure that you will always return to the exact same color and therefore, the same pH as when you started.
   1. Place 100 mL of room temperature, distilled water in a flask, add 2-3 drops of phenolphthalein.
   2. Add 0.1 N NaOH drop by drop until a light pink color is produced.
   3. Set the flask on white paper and use it as your standard color for all of the following tests.

B. Determining Respiration Rate: At rest
   1. Take your pulse while sitting down. Count for 15 seconds and multiply by four. Record this number. With the help of another student, also record your breathing rate for 1 minute.
   2. Place 100 mL of room temperature, distilled water in a flask. Add 2-3 drops of phenolphthalein. Add 0.1 N NaOH drop by drop until the water maintains the color of your comparison flask water.
   3. Using a straw, blow into the solution for 15 seconds.
   4. Add NaOH drop by drop, counting the number of drops needed to return to the water to the color of your comparison flask water. Record your results.

C. Determining Respiratory Rate: Brisk exercise
   1. Exercise briskly for 2 minutes by walking around the halls.
   2. Return to your seat and immediately take your pulse for 6 seconds and multiply by 10. Also record your breathing rate for 1 minute. Then blow through the straw into the flask for 15 seconds.
   3. Add NaOH drop by drop, counting the number of drops needed to return the water to the color of your comparison flask water. Record your results.

D. Determining Respiratory Rate: Strenuous exercise
   1. Exercise strenuously by running stairs for 2 minutes.
   2. Return to your seat and immediately take your pulse for 6 seconds and multiply by 10. Also record your breathing rate for 1 minute. Then blow through the straw into the flask for 15 seconds.
   3. Add NaOH drop by drop, counting the number of drops needed to return the water to the color of your comparison flask water. Record your results.

E. Analyze Results
   1. Place your results on the chalkboard.
   2. Discuss why there is so much variation between students, and what causes the different patterns of results. Relate the results to the amounts of carbon dioxide given off and the amount of ATP produced in aerobic and anaerobic respiration.

Modifying the Original Activity Implementing the Learning Cycle

To modify this activity, we started with the first phase of the learning cycle. The decision was made to begin with questions to encourage the students to explore the idea of what occurs in their body during physical exercise. We begin by asking the question,

"What physiological changes do you think occur in your body in each of the following cases:
as you sit comfortably,
as you change from sitting to walking,
and as you start to exercise vigorously?"

Student responses are taken and listed on the board. Responses typically include:

- breathing rate would increase,
- sweating would increase,
- body temperature would rise,
- heart rate would increase, etc.

Use of wait-time and positive non-verbal behavior (smiling, looking expectantly) is crucial to encourage all students to brainstorm and contribute ideas. By using extensive wait-time student responses may increase by as much as 300-700 percent (Rowe, 1986).

Because we want students to investigate the production of carbon dioxide, when students give breathing as an example, we ask,

"What are you breathing in and what are you breathing out?"

By using students' ideas, student motivation increases because students see that their ideas are valued. At the same time we get students to focus on the gases exchanged in their body. After sufficient time is given for all students to contribute to the list of ideas, we ask students,

"What are some of the different ways we could measure what your body does during physical activity?"

We provide students time to brainstorm individually, and then pair students to compare ideas. While paired, student groups were then directed to list their ideas on individual white boards. Student ideas often include tests like sitting and counting the number of breaths per minute and then counting the number of breaths per minute while walking around. Other student suggestions include testing heart rate before and after certain activities as well as testing the amount of carbon dioxide produced.

If students do not propose testing the amount of carbon dioxide produced during different activities, we guide the class toward this idea by asking questions such as,

"What else regarding your breathing could you test besides the rate?" or, more directly,
"How might the amount of carbon dioxide produced differ during different activities?"

At this point we might introduce to the class the procedure (from Figure 1) for testing carbon dioxide or discuss this procedure only with those groups who expressed interest.

After students have brainstormed ideas, we lead a class discussion in which students share their ideas and plans for testing. Allow students time to discuss options for testing, and accept all answers and methods of testing. This acceptance is crucial to help students make decisions and discuss their ideas openly and without judgment. If unsafe experimental procedures are an issue, raise the concern through questioning. As students are sharing their ideas we ask probing questions such as,

"How might the use of two different people as test subjects affect our results?" or
"What do we need to think about to make sure our tests are fair?"

Questions such as these help students identify and correct problems with their procedures. When a teacher asks questions rather than dictating changes, students shift from a reliance on the teacher to assessing the procedures themselves and determining improvements to their investigations.

Most student-generated tests are completely safe and, after our approval, students are given freedom to test. Because we had drawn students' attention to the exchange of gases during respiration many students are interested in investigating levels of carbon dioxide that are given off during exercise. A test can be done for this using NaOH, phenolphthalein, and water. While this is an important test for students to conduct, it is necessary to address several safety considerations and monitor students during their experiments. Students are also given a set of procedures to follow. During this safety discussion we instruct students on how to set up a comparison flask by following *Procedure A* from the original lab (Figure 1) and then pose the following questions,

"What is the value of setting up a comparison flask?"
"How will this be useful to you during your investigation?"

Since safety is an issue when students work with NaOH, we ask students what safety concerns they must consider when conducting this test. One of the major safety concerns is that students must blow into the straw, but not suck any liquid up from the flask. Sometimes students do not raise this concern on their own. When this happens we explicitly raise this issue by demonstrating blowing into the straw, pausing for a moment, then stopping the demonstration and posing the following questions,

"What might a careless student with the straw in their mouth do next that would be a safety hazard?"
"If a student removes the straw from the flask with the intention of reusing the straw, what safety concern should be considered?"

Students are quick to identify that they need to be careful to not suck liquid up from the flask and to always keep the same side of the straw in the liquid so their lips do not come into contact with the liquid.

Students have now been given approval of their investigations and are set off to test what changes occur within their bodies during exercise. During this time we move from group to group and observe, interact with, and pose questions to students on how they are measuring the changes taking place on their bodies. Questions that we often pose to students include,

> "How are you testing the changes in your body that occur due to exercise?"
> "Why have you decided to test ______? How will you analyze your results?"
> "What have you started to discover happening to your _____ (body, breathing rate, pulse rate, amount of carbon dioxide produced, etc) as you exercise? Why do you think this occurs?"
> "How strenuousness did you work your body in this exercise as compared to previous trials? What do you think this implies about how long you could continue this exercise?"

When testing is completed, groups report their findings to the class. Students realize that there were many different ways to test the changes taking place within the body during exercise. During this discussion students are compelled to think about their data through questions such as,

> "How are these experiments/tests similar?"
> "How are they different?"
> "How do the different test results support or not support each other?"

Students notice that multiple types of experiments were conducted in a number of ways. This discussion provides an opportunity to discuss the importance of variables with the students.

As students report their findings to the class, they start to notice trends in the data. Students notice that while heart rate and breathing rate increased in all individuals, carbon dioxide production increased in some individuals but decreased in most. When students inquire about this difference in the carbon dioxide levels the teacher can make a transition from the exploratory phase of the learning cycle to the concept development phase.

To help explain their observations about carbon dioxide production, and because students now have a desire to learn new material, the teacher now introduces the terms "aerobic respiration" and "anaerobic respiration". The equations for aerobic and anaerobic respiration were written on the board.

Aerobic respiration: $C_6H_{12}O_6 + O_2 \quad 6CO_2 + 6H_2O + 36ATP$
Anaerobic respiration: $C_6H_{12}O_6 \quad 2CO_2 + \text{Lactic Acid} + 2ATP$

We pose the question,

> "How might these equations help explain your data?"

Students notice that when compared to aerobic respiration, anaerobic respiration produces much less carbon dioxide. This idea helps students make the connection between what they observed in their carbon dioxide levels after exercising and the equations for aerobic and anaerobic respiration. For students to make the desired conceptual connections the teacher must often ask explicit questions to help students make links between the equations and the tests the students had conducted.

If students struggle to make links the teacher can scaffold student thinking by asking questions such as,

> "What do you notice about the amount of carbon dioxide produced in each equation?"
> "How can these equations help explain your observations?"

If students continue to struggle the teacher must take into account what students are saying and carefully guide students to make connections. During these discussions the teacher must use extensive wait-time and encourage all students to provide ideas by not rejecting or confirming student comments (Abraham & Schlitt, 1973). We also encourage students to explain their thinking. Based on students' comments decisions are made about how to move the discussion forward so that all students make these important conceptual links. For example, we might have students apply their knowledge by designing an experiment trying to determine their individual aerobic threshold, which investigates at what point their body switches from aerobic to anaerobic respiration.

Comparing Traditional to Inquiry-based Activities

We were interested in looking at how student lab conversations differ between inquiry-based learning cycle lessons and traditional lessons, and how inquiry-based learning affected students' test scores. We introduced the concepts of aerobic and anaerobic respiration to four classes of 10^{th} grade General Biology students. With two of the classes we taught the concepts through a more traditional approach by using the preset step-by-step procedure. With the other two classes we modified the activity to make it more inquiry-based as described above. By looking at student comments during the lab, and test scores following the unit, we determined the impact of introducing a new concept with the learning cycle and inquiry.

We collected student comments by observing, listening to, and recording their comments during the activity. We would generally write down the first comment or two that we would hear, attempting to ensure the group was not distracted by our presence. We grouped the comments into three main categories. The comments were either procedural, conceptual, or students were off-task. Students receiving traditional instruction were more concerned with procedural tasks (Table 1). Since students were provided detailed procedures, their focus was directed entirely on following each step, which shifted their focus away from mental engagement of the concept. *The traditional lab was hands-on, however students were not encouraged to mentally engage the material to any considerable extent*. In contrast, the students who performed the modified activity asked many conceptual questions and discussed comments with one another as they performed the lab. This modified activity was both physically and mentally engaging.

Examples of comments by students who received traditional instruction included:

- "How do we calculate our breathing rate?"
- "Should we copy down the data table?"
- "How do we add drops of carbon dioxide, I mean NaOH?"
- "What should I do for strenuous exercise?"
- "Is this the right color?"
- "So…do we do this all again?"

In contrast, what follows is a conversation between students during the modified activity. This conversation illustrates how students were more concerned with conceptual details rather than procedural, although the procedures were still relevant.

Student 1:"What is strenuous?"
Student 2: "It probably depends on how in shape you are."; "WOW! I hardly produce any carbon dioxide I must be out of shape!"; "The clock stopped! That's another variable!"
Student 1: "I'm just going to run in place."
Student 2: "No, because that is another variable in the experiment and we would be different from the rest of the class."

To further assess the use of the modified activity against the traditional activity we analyzed student test scores. First, we compared prior exam scores to analyze the difference between the two groups prior to this activity. We determined that the average score on tests prior to this unit was similar between the two groups (Table 2). The prior test scores show a small difference in test averages between the two sections. Table 2 also displays the comparison of the two groups for their test scores at the end of the unit containing the aerobic/anaerobic concept. The average test scores were higher for students who completed the modified activity. In addition, one specific question on the exam asked students to "Describe three differences between Aerobic and Anaerobic respiration." The average score on this question for students from the traditional activity was 1.7 points out of 3 points. The average score for the students performing the modified activity was 2.3 points out of 3 points.

TABLE 1
Comparison of Students' Comments: Inquiry versus Traditional

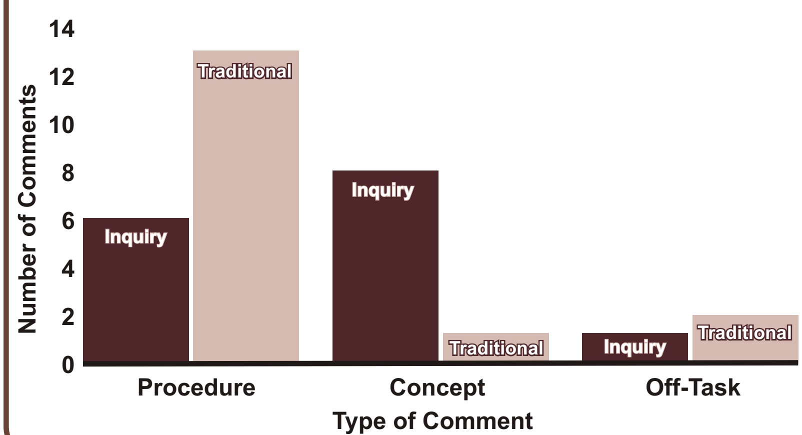
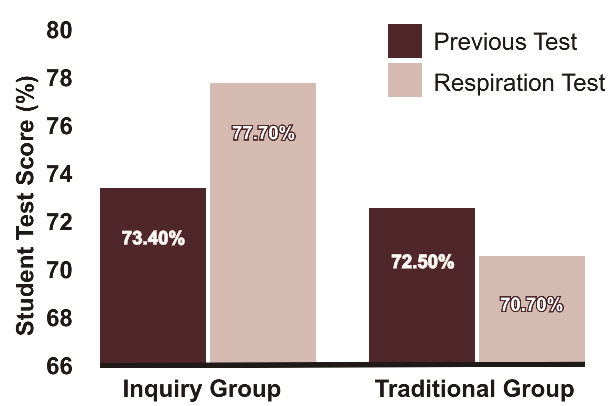


TABLE 2
Comparison of Test Score Averages: Previous Test vs. Respiration Test



Expectation and Outcome Differences between Traditional and Inquiry-Based Activities.

As teachers we have goals we strive to promote in our classroom. Goals that are addressed in the modified activity include that students will:

1. develop a deep and robust understanding of science concepts.
2. develop investigative and procedural skills.
3. develop increasing higher order thinking (problem solving, critical thinking, deductive and inductive reasoning, proportional reasoning, etc.)
4. develop creativity, curiosity, and imagination.
5. work well both cooperatively and independently.
6. understand the nature of science.

The original activity had students working with the complex biological topics of aerobic and anaerobic respiration. While using traditional instruction promoted two of our student goals (#2 and #5), we felt students were being cheated out of rich opportunities to better engage with science content. The original activity required students to simply follow step-by-step procedures, so they miss opportunities to wrestling with mentally stimulating ideas. Many students may complete the activity without understanding the concept because they "checked out" mentally during the activity.

By requiring students to become decision makers, the modified activity promoted deeper thinking and placed more responsibility on students. This increased demand for student responsibility does not negate the crucial role of the teacher! At times students would become stuck, at which time the teacher jump starts discussion by asking questions such as,

"How might you test this question?"
"What additional information do you need to collect?"
"What new questions do you have as a result of the data you collected?"

It is important to note that the teacher's own mental effort is increased during the modified activity. Student questions and problems are difficult to foresee, and guiding students to overcome difficulties can be difficult. Yet through the modified activity students were asked to exhibit higher order thinking skills to solve the problems at hand. The modified activity promotes not only procedural skills, but also investigative skills. We feel that both of these goals are important for students in our classroom.

Another advantage of the modified activity is the level of creativity, curiosity and imagination displayed by students. This important goal for students was completely absent in the original activity which was not the fault of the students, but of the activity itself. In addition, students completing the revised activity worked both cooperatively and independently. In the original activity, all students were to perform the same experiment in the same way. In the modified activity, students developed their own unique experiments and then reported their findings to the class. When students use creativity and imagination, they also develop a more accurate understanding of the nature of science (McComas et. al., 1998). Students often see science as dull, follow-the-directions type work, yet real science requires great creativity and ingenuity. Having students conduct an activity that requires them to design a procedure can help illustrate science as a creative endeavor. Furthermore, explicitly drawing students' attention to how they made use of creativity to interpret their data, and how they worked together towards a common goal, helps deepen students' understanding of how science really works.

Final Thoughts

While modifying traditional science activities takes significant time and effort by the teacher, the benefits are undeniable. This action-research study helped convince us that when students are mentally engaged with science content through inquiry experiences their content understanding improves. When students are not simply told answers and are asked to wrestle with and discuss concepts, not only are they more engaged in the content, they are also learning valuable life lessons including communication, teamwork, problem-solving, creativity, and persistence. Even though the amount of teacher effort and class time required to complete the activity may increase, the multitude of benefits for students make activities such as the modified activity here presented exceptionally worthwhile.

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