Using Pulse Oximetry to Illustrate Homeostasis in the Secondary Biology Laboratory

**AbstrAct**

To survive, complex organisms must maintain homeostasis by coordinating the activity of interacting, hierarchical systems. This is a core biological idea in the Next Generation Science Standards and one that many students find challenging. The most common lab exercise used to introduce homeostasis – a mini-experiment in which students measure how physical activity affects their pulse and respiratory rate – fails to show any direct evidence of internal stability. In this article, we describe how modifying this lab using an inexpensive pulse oximeter rectifies this shortcoming, giving students the ability to collect laboratory data that show both change and dynamic stability.

**Key Words:** homeostasis; science education; laboratory exercises.

**Introduction**

Homeostatic regulation – the maintenance, by organisms, of largely stable internal conditions – is a canonical characteristic of life. Complex organisms achieve homeostasis by coordinating the activity of interacting, hierarchical systems. Vascular plants, for instance, must harmonize the workings of their root and shoot systems; humans need their circulatory, endocrine, and digestive systems (among others) working in concert. Moreover, homeostasis is an important part of the Next Generation Science Standards, both within disciplinary core idea LS1.A: Structure and Function and as an exemplar of the crosscutting concept Stability and Change (NGSS Lead States, 2013). Additionally, homeostasis provides an example of the sort of systems thinking needed to understand phenomena like climate change (see Goldstone & Wilensky, 2008).

Despite its importance, students struggle to understand homeostasis for a number of reasons. First, understanding homeostasis requires thinking of organisms as systems, and systems-based reasoning, including the feedback loops that characterize homeostatic regulation, is difficult for students (Assaraf et al., 2013). To make matters worse, we rarely provide a full account of why life requires homeostasis. Why do organisms need so much water, a particular concentration of salts, this or that pH in the bloodstream? Teachers have insufficient time to provide full explanations for every homeostatically regulated parameter in an organism, and so even students who partially understand homeostasis may internalize an essentialist version of it, interpreting it to mean that the body is kept completely static and unchanging (Westbrook & Marek, 1992).

The persistence of students’ struggles here may be partially explained by the fact that it is very difficult to measure (or otherwise “see”) internal stability. Indeed, many of the most common introductory labs about homeostatic processes – like the “Making Connections” lab required in New York State, which asks students to measure their pulse and/or breathing rates before and after various forms of exercise (New York State Education Department, 2002) – produce direct evidence only of physiological change. Because students measure only changing variables like pulse rate, they may miss the key concept that underlying internal conditions – blood oxygen levels, in this case – remain within narrow limits. (Or worse, students may take increased heart rate to be the outcome of homeostasis, rather than a means to it!) By revising this lab to include pulse oximetry, a simple and inexpensive method of measuring blood oxygen saturation (see Figure 1), we have developed a procedure that allows students to see both stability and change and, in turn, to reason more comprehensively about homeostasis.

**Pulse Oximetry: Background**

Normal human blood oxygen saturation – that is, the proportion of oxygenated hemoglobin binding sites in arterial blood – is around 95%. In healthy individuals, oxygen saturation levels are maintained by aerobic respiration and do not typically show significant

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fluctuations, even during strenuous exercise. Pulse oximetry provides a fast and largely reliable estimate of blood oxygen saturation (called SpO$^2$) that takes advantage of the fact that oxygenated and deoxygenated hemoglobins absorb differential amounts of infrared and red light (see Jubran, 2015).

Using a pulse oximeter offers several advantages over the traditional approach to a pulse-rate lab (e.g., New York State Education Department, 2002), in which students use a stopwatch to manually take their pulse. Students do not have trouble finding their pulse, as the device clearly displays it on the screen. Measurements are therefore faster and do not require cessation of exercise, which (slightly) confounds results. Most importantly, the SpO$^2$ data provide students with a key index of physiological stability during exercise.

**Intended Audience & Prior Knowledge**

This activity was conducted over a single lab period in a Living Environment course (New York State’s name for biology), which students typically take between eighth and 10th grade. Students should be familiar with the circulatory system and need basic knowledge of cellular respiration. The second author has used this lab both as an opportunity for students to demonstrate mastery toward the end of a unit on homeostasis, and earlier in the unit as an investigative phenomenon (NGSS Lead States, 2016) that motivates additional instruction.

**Materials & Setup**

The materials and setup for this laboratory are minimal. Each lab group (we had students in pairs, though groups could be larger) will need the following:

- Inexpensive, fingertip pulse oximeter (sanitized before use)
- Stopwatch
- Graph paper or software for graph creation
- 70% isopropanol and paper towels

Before students arrive, arrange desks so that student groups have enough room to safely perform exercises (usually jumping jacks) during data collection. If desks must be moved aside, consider providing students with clipboards.

**Safety Precautions**

As students exercise, instruct them to do so with closed hands to prevent the pulse oximeter from flying across the room. Additionally, allow groups to choose an alternative exercise as needed to accommodate different fitness levels and/or medical conditions. Consider checking for medical conditions with the school nurse – alternatively, older students can self-screen using the PAR-Q+, as recommended by the American College of Sports Medicine (see PAR-Q+ Collaboration, 2020).

**Procedure**

Begin by reviewing the pre-lab background information (see Supplemental Material available with the online version of this article) and elicit students’ hypotheses about how exercise will affect heart rate and blood oxygen saturation. Model for students the use of the pulse oximeter, including how to hold it during exercise to prevent the oximeter from falling off.

**Data Collection**

Students should measure and record their resting pulse rate and SpO$_2$. Then, as one student (A) starts the timer, the other student (B) should begin two minutes of exercise. Every 15 seconds, student A should ask student B for pulse and SpO$_2$ readouts, and record the results. After two minutes, exercise should cease, and data should be collected for two additional minutes. Students should then wipe down the oximeter with isopropanol, switch roles, and repeat. During data collection, circulate and ask students questions to check their understanding (for a list of leveled questions that provide differentiated support, see Appendix). After both students collect data, they should each create a double y-axis line graph of their pulse rate and SpO$_2$ over time, annotating where exercise started and stopped (Figure 2).

**Figure 1.** A common fingertip pulse oximeter showing both an estimate of blood oxygen saturation (SpO$_2$) and pulse rate in beats per minute (PR-bpm) (image source: https://upload.wikimedia.org/wikipedia/commons/b/b5/OxyWatch_C20_Pulse_Oximeter.png).

**Figure 2.** Sample line graph showing pulse rate and oxygen saturation during two minutes of exercise and two minutes of recovery.
Class Discussion
Facilitate a class discussion about common themes in students’ results. If it has not already happened spontaneously, consider challenging a student group to try and intentionally lower their SpO₂ through two minutes of intense (but still safe) exercise. If, during the discussion, students demonstrate firm command of fundamental homeostasis concepts, elicit their ideas about mechanism – that is, how the body might “know,” at a cellular/molecular level, to increase the heart or breathing rate. Emphasize the dynamic equilibrium at play – increased consumption of oxygen is offset by greater intake (deeper breathing) and faster delivery (increased heart rate) – and have students connect this to the conceptual meaning of homeostasis. Afterward, students might work in groups to complete a series of analysis questions (see Supplemental Material) or to put the room back in order.

Possible Alterations & Extensions
To extend this lesson for a longer period of time or to bring in connections to the nature of science, consider beginning the activity by teaching students to measure their pulse manually (two fingers over the wrist, a stopwatch, some mental math). This approach helps students better appreciate the convenience of the oximeter, and it may occasion a teachable moment about precision and measurement error.

Also, as mentioned, this activity can be framed as the production of a phenomenon rather than a standard lab exercise. If students perform the activity before receiving significant instruction about homeostasis, the result (stable levels of SpO₂ before, during, and after exercise) may well strike them as a mystery deserving of further investigation. The use of phenomena in instruction provides a motivational boost, but it also enables ambitious (and NGSS-aligned) forms of science teaching when paired with certain kinds of model-based sensemaking activities (see Windschitl et al., 2018). A phenomenon-based approach might also facilitate later instructional connections to situations where SpO₂ does not remain constant, such as in high-altitude mountaineering or in certain respiratory diseases.

Finally, the lab can be extended by measuring additional variables. For instance, students could measure ventilation rate and depth before, during, and after exercise. This adds complexity to the data collection process, but it enables a deeper exploration of the interaction between the circulatory and respiratory system and the investigation of physiological concepts like alveolar ventilation (e.g., Hallett et al., 2020).

Classroom Observations
The second author has used this activity to supplement the state-required homeostasis lab for the past three years. In lab reports and class discussions, students have consistently connected their results to the importance of both stability and change in the maintenance of homeostasis. Additionally, students enjoy the biofeedback provided by the oximeter, and frequently engage in (motivating, if scientifically less than rigorous) competitions to achieve the highest heart rate or an intentional change in SpO₂. These additional trials have allowed students to draw on tacit understandings about body systems and the nature of science to identify subject-level variables that might be impacting pulse rates – differences in the intensity of exercise or base levels of cardiovascular fitness, larger or smaller bodies/organs, and so on. Such discussions further increase the relevance of the material to students’ lives and reinforce the complex set of conditions under which homeostatic regulation operates.

Incidentally, we have seen only one student lower their blood oxygen level by even one point. This is presumed to mean that SpO₂ was actually lowered not by an entire percentage point, but by just enough to fall below the threshold of an inexpensive machine that measures in whole percentages. Providing students with hard evidence of stability through this lab emphasizes this often-overlooked aspect of homeostasis.

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References

Assaraf, O.B., Dodick, J. & Tripto, J. (2013). High school students’ understanding of the human body system. Research in Science Education, 43, 33–56.

Goldstone, R.L. & Wilensky, U. (2008). Promoting transfer by grounding complex systems principles. Journal of the Learning Sciences, 17, 465–516.

Hallett, S., Toro, F. & Ashurst, J.V. (2020). Physiology, Tidal Volume. In StatPears [e-book]. Treasure Island, FL: StatPears. https://www.ncbi.nlm.nih.gov/books/NBK482502/ [retrieved August 2020].

Jubran, A. (2015). Pulse oximetry. Critical Care (London), 19, 272.

New York State Education Department (2002). Making connections: a laboratory activity for the Living Environment [curriculum document]. http://www.goldiesroom.org/AP%20Biology/AP%20Labs%20pdf/v2013/AP%20Lab%20Making%20%20%20pdf.pdf [retrieved May 2020].

NGSS Lead States (2013). Next Generation Science Standards: For States, by States. Washington, DC: National Academies Press.

NGSS Lead States (2016). Phenomena [web page]. Next Generation Science Standards: For States, by States. https://www.nextgenscience.org/resources/phenomena.

PAR-Q+ Collaboration (2020). 2020 PAR-Q+ [instrument]. [retrieved August 2020].

Westbrook, S. & Marek, E. (1992). A cross-age study of student understanding of the concept of homeostasis. Journal of Research in Science Teaching, 29, 51–61.

Windschitl, M., Thompson, J. & Braaten, M. (2018). Ambitious Science Teaching. Cambridge, MA: Harvard Education Press.

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Appendix: Sample Questions to Ask during Data Collection

These questions are designed to check for student understanding. The levels are based on students’ perceived current learning needs. Modify, cut, or add to this list to make it work for your style and your students.

**Level A Questions:** *(Recall of necessary background information and laboratory procedures)*
- What is the function of the circulatory system?
- How many seconds are you waiting between measurements?
- What two measurements are you using your pulse oximeter to measure?
- Who is doing jumping jacks first?
- For what biological process do we need oxygen?

**Level B Questions:** *(Finding relationships between variables)*
- How are activity and pulse rate related?
- How are activity and SpO\textsubscript{2} related?
- Just using the data from your graph, at what point did you stop exercising? How do you know?
- Why did your pulse rate decrease after you stopped exercising?

**Level C Questions:** *(Application, extension, challenge)*
- What would your graph look like if you kept exercising for 10 minutes?
- What would happen to your SpO\textsubscript{2} if you kept exercising for 10 minutes? Use the data from your graph to support your answer.
- Why did your SpO\textsubscript{2} stay the same even though your activity and pulse rate increased?
- How do you think your results would change if you had a smaller-than-average heart? Larger-than-average? Why?
- What might happen to your pulse rate if you began inhaling pure oxygen during the activity and your SpO\textsubscript{2} was at 100%?
- Do you think the SpO\textsubscript{2} of hibernating bears would look different from that of active bears? Why or why not?
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