

Homeostasis and Negative Feedback – Concepts and Breathing Experiments¹

I. Homeostasis and Negative Feedback

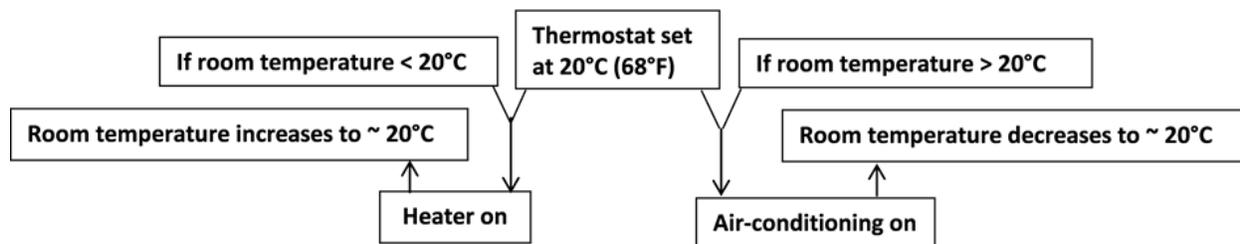
Homeostasis refers to the maintenance of relatively constant internal conditions. For example, your body maintains a relatively constant body temperature even when the external environment gets colder or hotter.

1. Describe one way your body responds to a cold environment, and explain how this response helps to keep your body temperature from falling too low.

2. Describe one way your body responds to a hot environment, and explain how this response helps to keep your body temperature from rising too high.

These body responses are an example of negative feedback. **Negative feedback** occurs when a change in a **regulated variable** triggers a response which reverses the initial change and brings the regulated variable back to the **set point**.

This flowchart shows negative feedback regulation of temperature in a home with central heating and air-conditioning. Negative feedback maintains the regulated variable (room temperature) relatively constant at approximately the set point (20°C).



3. Draw a similar flowchart to show negative feedback regulation of body temperature. (The thermostat for body temperature regulation is in the brain and normally has a set point of ~37°C.)

¹ By Drs. Ingrid Waldron, Lori Spindler and Jennifer Doherty, Dept of Biology, University of Pennsylvania, © 2017. Teachers are encouraged to copy this Student Handout for classroom use. A Word file, which can be used to prepare a modified version if desired, and Teacher Preparation Notes with background information and instructional suggestions are available at http://serendipstudio.org/sci_edu/waldron/#breath.

4. Why is negative feedback regulation of body temperature useful? What are some biological or health problems that can occur if your body temperature gets too high or too low?

5. Explain how negative feedback contributes to homeostasis.

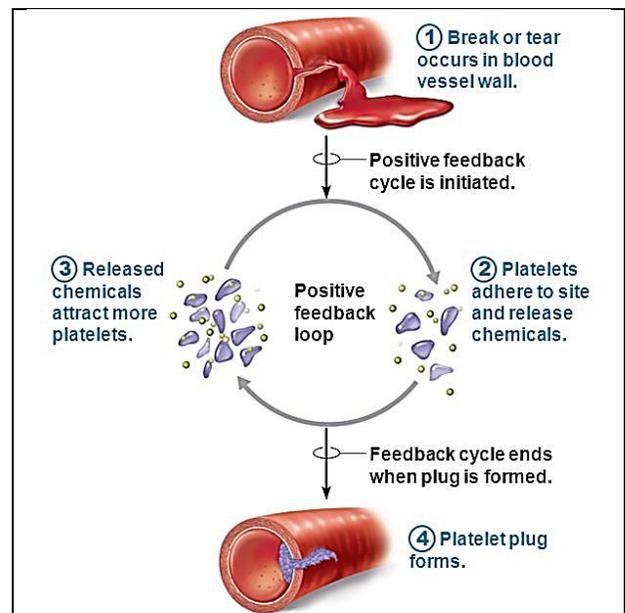
Two Types of Feedback:

Negative feedback occurs when a change in a variable triggers a response which reverses the initial change.

Positive feedback occurs when a change in a variable triggers a response which causes more change in the same direction.

This figure shows how positive feedback contributes to the rapid formation of a platelet plug in an injured blood vessel. The injured area attracts platelets, and each of these platelets secretes chemicals that attract more platelets. Thus, many platelets accumulate quickly and together these platelets plug the hole in the injured blood vessel and prevent excessive blood loss.

6. Explain how this example illustrates the general principle that "Positive feedback is useful when there is an advantage to making a rapid change."



7. Shivering in a cold environment can raise your body temperature. Is shivering part of positive feedback or negative feedback? Explain your reasoning.

8. What would go wrong if your body used positive feedback to regulate body temperature? For example, what would happen if a person sweated when temperature decreased?

II. Respiration and Circulation

This page provides helpful background for the experiments you will be doing on negative feedback and breathing.

All the cells in your body need energy to do their work. For example, muscle cells need energy to contract. The energy for muscle contraction and most other cellular processes is provided by ATP molecules. Most of the ATP in your cells is produced by cellular respiration which uses O_2 and produces CO_2 .

During inhalation the breathing muscles expand the lungs; this brings fresh air with needed O_2 into the lungs. During exhalation the lungs get smaller and air with excess CO_2 is pushed out of the lungs.

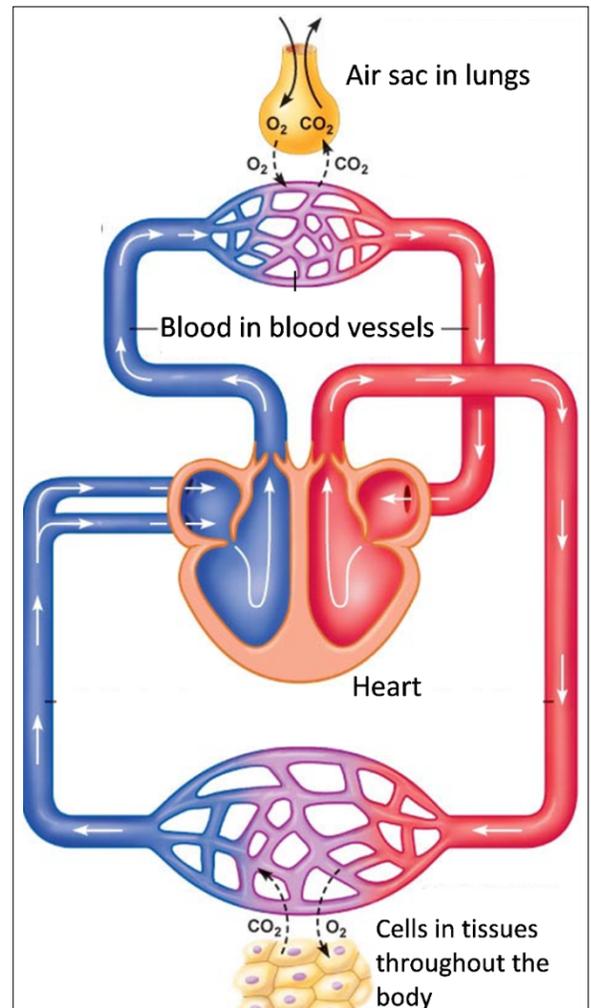
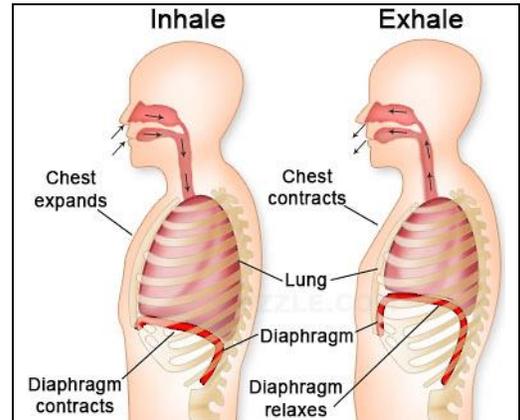
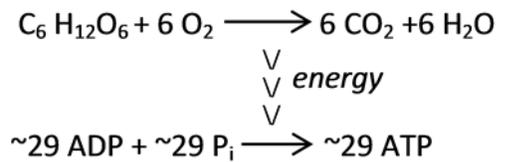
9. When you are physically active, contracting muscle cells use lots of ATP, so the rate of cellular respiration increases. How does your breathing change during physical activity? Why are these changes useful?

In your lungs there are millions of tiny air sacs, each surrounded by many tiny blood vessels. This figure shows how O_2 diffuses from the air in these air sacs to the blood in the surrounding blood vessels. Then blood with O_2 is pumped by the heart through larger blood vessels to tiny blood vessels near each cell in your body. There, the O_2 diffuses from the blood into the cells.

10. Draw a single long arrow to show how CO_2 moves from the cells of the body via the blood to the air in the air sacs of the lungs.

11. The respiratory system includes the lungs, nose and tubes that carry air to and from the lungs. The circulatory system includes the heart, blood and blood vessels. Explain why a person needs to have both a respiratory system and a circulatory system to provide the body's cells with the O_2 needed for cellular respiration.

Cellular Respiration of Glucose



III. Negative Feedback and the Regulation of Breathing

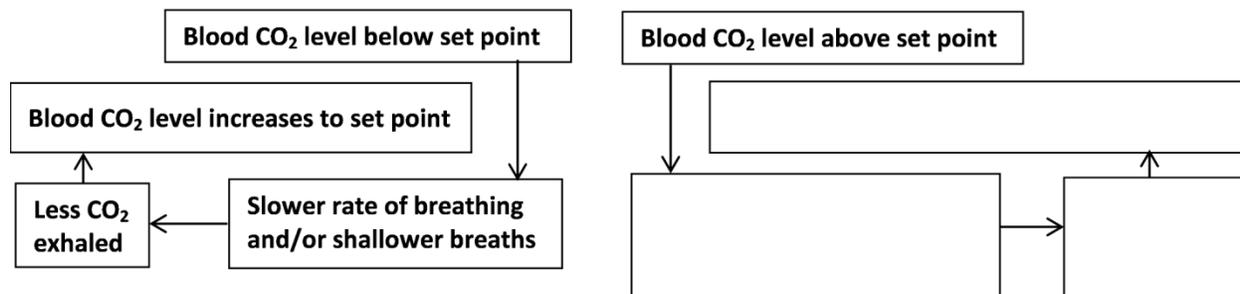
Your brain regulates the rate and depth of your breathing to match the needs of your body for O₂ intake and CO₂ removal. Breathing rate refers to the number of breaths per minute. Depth of breathing refers to the amount of air taken in with each breath.

12a. On the top of a high mountain, air pressure is significantly lower than at sea level, so there is less O₂ in a given volume of air. Suppose a person at high altitude maintained the same rate and depth of breathing as he had at sea level. What would happen to the O₂ levels in his blood? Explain your reasoning.

12b. What changes in breathing could maintain relatively constant O₂ levels in the blood for a person who has gone from sea level to high altitude?

When blood levels of O₂ and/or CO₂ get too low or too high, negative feedback regulation restores these blood levels to a healthy set point. This negative feedback regulation can increase or decrease the rate and/or depth of breathing.

13. Complete this flowchart diagram to show how negative feedback regulation could change the rate and/or depth of breathing to maintain relatively constant levels of CO₂ in the blood.



Next, you will do an experiment to investigate how negative feedback regulation of blood levels of CO₂ and O₂ influences the rate and depth of breathing. In your experiment, each subject will breathe the air in an 8 gallon plastic garbage bag for four minutes.

14. Based on the negative feedback hypothesis, predict how your breathing will change by the end of four minutes of breathing into the plastic bag. Explain your reasoning. (Hint: Think about what will happen to the CO₂ and O₂ levels in the air in the bag and in the air in your lungs as you breathe into the bag for several minutes.)

Developing Your Experimental Procedures

For a scientific investigation to yield accurate results, scientists need to begin by developing reliable, valid methods for measuring the variables in the investigation.

- Each person in your group of four students should get an 8 gallon plastic garbage bag. Your group will also need some way to time 30 second intervals during the experiment.
- To prepare to breathe into the bag, open your bag completely and swish it through the air until the bag is nearly full of air; then gather the top of the bag in both hands and use your finger to open a small hole in the center just big enough to surround your nose and mouth; hold this opening tightly over your nose and mouth. (If you have asthma or some other breathing difficulty, check with your teacher about whether you should breathe into a bag.)
- To evaluate the rate and depth of breathing, watch how a crease in the bag changes as the person breathes in and out.
- Practice evaluating the rate of breathing. One person in your group should breathe into his or her bag, while another person times 30 seconds, and the other two count the number of breaths. Record your count before you say the number out loud. _____. If your results are not in agreement (difference of more than one breath), discuss possible reasons for the differences and try again. Next, switch roles to have a new subject and timer and two new observers.
- Practice evaluating the depth of breathing (how much air a person breathes in and out in each breath). One of you should breathe into your bag for 3 minutes while another person times 30-second intervals. The other two people in your group should use the following rating system to record the depth of breathing in each 30-second interval:
 - Start with 1 for the depth of breathing in the first 30-second interval.
 - Increase your number by 1 for any interval where you observe a clear increase in depth of breathing.
 - Decrease your number by 1 in any interval where you observe a clear decrease in depth of breathing.
 - If the depth of breathing doesn't change significantly from one interval to the next, repeat the same number you had for the previous interval.

| Time Interval (minutes: seconds) | 0:00-0:30 | 0:30-1:00 | 1:00-1:30 | 1:30-2:00 | 2:00-2:30 | 2:30-3:00 |
|----------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Rating for depth of breathing | 1 | | | | | |

Record your results without commenting to each other. Then, compare your results, discuss the criteria you used, and try to agree on reliable procedures for rating the depth of breathing. Next, switch roles to have a new subject and timer and two new observers. If both observers have similar results, summarize your procedures for rating the depth of breathing. If your results differ significantly, improve your procedures and try again.

Doing the Experiment

- You will carry out your experiment four times; each time a different group member will be the experimental subject. Each subject will breathe into the bag for 4 minutes (or 3½ minutes if you start to feel too uncomfortable and can't continue for the full 4 minutes). For each experimental subject, the other three people in the group will observe and record the data in question 15 on the next page.
 - Experimenter 1 will time each 30 sec. Interval.
 - Experimenter 2 will count and record the number of breaths in each 30 sec. interval.
 - Experimenter 3 will assess and record the depth of breathing during each 30 sec. interval.

15a. Record the results for each subject in the appropriate columns; if a subject stops breathing into the bag before the end of the 4 minutes, put an X in the remaining boxes.

| Time Interval (minutes: seconds) | Number of Breaths in 30 sec. Interval for Subject: | | | | | Depth of Breathing for Subject: | | | | |
|--|---|---|---|---|------|------------------------------------|---|---|---|------|
| | 1 | 2 | 3 | 4 | Ave. | 1 | 2 | 3 | 4 | Ave. |
| 0:00-0:30 | | | | | | 1 | 1 | 1 | 1 | 1 |
| 0:30-1:00 | | | | | | | | | | |
| 1:00-1:30 | | | | | | | | | | |
| 1:30-2:00 | | | | | | | | | | |
| 2:00-2:30 | | | | | | | | | | |
| 2:30-3:00 | | | | | | | | | | |
| 3:00-3:30 | | | | | | | | | | |
| 3:30-4:00 | | | | | | | | | | |

15b. Immediately after you finish breathing into the bag, describe any changes you noticed in your breathing toward the end of your four minutes of breathing into the bag.

15c. Use an * to mark the columns in the table that have your data. Describe any differences between these results and the changes you recorded in 15b. What might account for these differences?

Analyzing and Interpreting the Results of the Experiment

16a. A student group found the following results for the last two 30 sec. intervals. Since the average number of breaths in both of these 30 sec. intervals was 9, the group concluded that the breathing rate did not increase in the last interval. Explain why this conclusion is *not* valid.

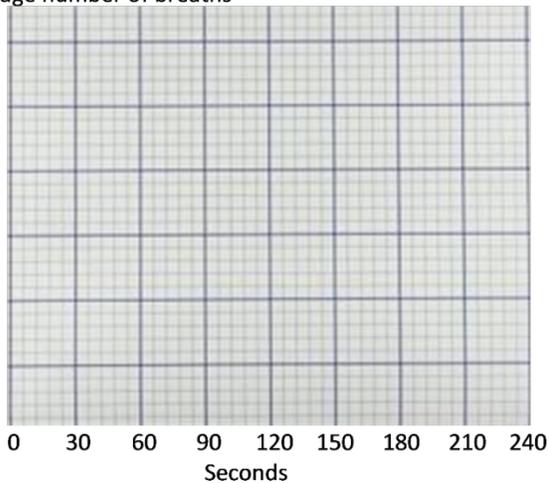
| Time Interval (minutes: seconds) | Number of Breaths in 30 sec. Interval for Subject: | | | | |
|--|---|---|---|----|------|
| | 1 | 2 | 3 | 4 | Ave. |
| 3:00-3:30 | 8 | 8 | 8 | 12 | 9 |
| 3:30-4:00 | 9 | 9 | 9 | X | 9 |

16b. Did any of the subjects in your group stop breathing into the bag before the end of the four minutes? If yes, describe a strategy you can use to avoid the type of misleading comparison described in question 16a.

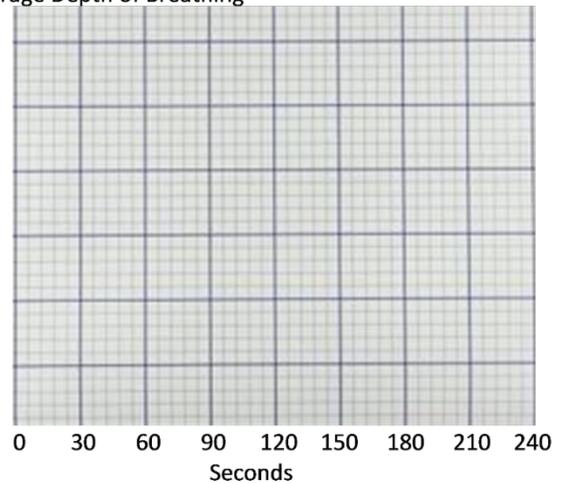
17. Calculate the average number of breaths and average rating for depth of breathing for each 30 sec. interval in question 15a. If needed, use the strategy you described in question 16b.

18. Plot your data to show the average number of breaths and average depth of breathing in each 30 sec. interval. (Label the Y axis for each graph.)

Average number of breaths



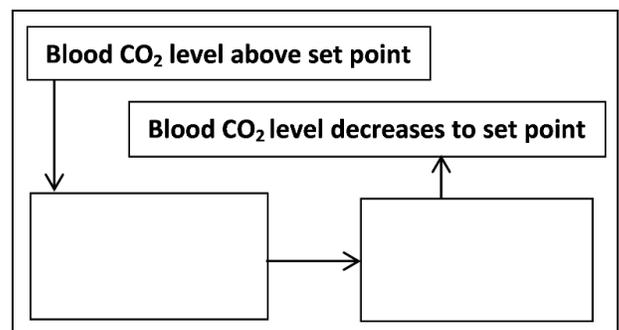
Average Depth of Breathing



19. Briefly describe the trend in average number of breaths per 30 sec. interval. Does this trend match your prediction based on the negative feedback hypothesis? (See question 14.) Briefly summarize the similarities and/or differences between your observed results and your prediction.

20. Briefly describe the trend in average depth of breathing. Does this trend match your prediction based on the negative feedback hypothesis? (See question 14.) Briefly summarize the similarities and/or differences between your observed results and your prediction.

21a. Scientific evidence indicates that any changes in breathing that you observed were primarily due to changes in concentration of CO₂ (not O₂). Based on your group's experimental results, complete this flowchart diagram to show how negative feedback regulation changed the rate and/or depth of breathing.



21b. Compare this flowchart based on your group's experimental results with the right half of the flowchart in question 13. Are there any differences? If yes, which of your experimental results contributed to these differences?

22. If you were going to repeat this experiment, what changes in method could improve the accuracy of your experiment?

IV. Homeostasis and Changes in Breathing Due to Exercise

23. When a person exercises, his or her muscle cells use much more ATP per second than when he or she is resting. Therefore, the rate of cellular respiration is much higher during exercise. What changes in breathing would help to maintain homeostasis during exercise? Explain your reasoning.

24. Think about your experience and your past observations concerning changes in breathing during and after exercise. Summarize three of your observations in the first column of this table. In the second column, indicate how certain you are about each of these observations. In the third column, explain how each observation relates to homeostasis during and after exercise.

| Your observations about changes in breathing during and after exercise | Very certain, Fairly certain <u>or</u> Uncertain | How each observation relates to homeostasis |
|--|--|---|
| | | |
| | | |
| | | |

25. What is one question you want to investigate to gain additional information about how breathing changes as a result of exercise? You should choose a question that:

- will provide you with new information beyond what you already know
- can be investigated in your classroom.

Develop a plan for an experiment to answer your question. Your teacher will recommend a method for measuring the rate and depth of breathing. Before beginning your experiment, you should practice this method and develop reliable and valid measures of rate and depth of breathing. You may want to develop criteria for three categories of depth of breathing, e.g. quiet breathing, intermediate depth of breathing, and very deep breathing.

Feasible methods for measuring breathing rate and depth generally do not work well when a person's head is moving, so you will probably need to compare breathing rate and depth before each subject begins exercising vs. breathing rate and depth right after the end of exercise and at intervals during recovery.

Answer the following questions on a separate page or pages.

26. Describe the procedure for your experiment. Be specific about the sequence of steps in your procedure, including:

- what you want your subjects to do and how you will standardize the exercise to be similar for each member of your group
- when and how you will measure breathing.

Your teacher will check your group's plan for your experiment and may help your group improve your experimental procedure. Incorporate any needed changes in your description of your procedure.

27. Make a data sheet for collecting the data during your experiment. The data sheet should include places to record:

- all the breathing data for each student in your group
- observations on each person's exercise
- anything else you notice that might affect the results.

28. Plan how you will analyze your group's data to answer your question. If you will be calculating averages, decide which measurements will be included in each average. If you will be making graphs, decide what type of graph you will use and what variables you will include. Your plan should include some way to summarize your results in a table and/or graph that will help you to answer your question.

Your teacher will check your data sheet and your plan for how to analyze the data and may suggest improvements.

➤ Carry out the experiment for each subject in your group, and record your data in the data sheet.

29. Analyze your data, and prepare a brief report that includes:

- your graph or other summary of your results
- your interpretations of your data and conclusions concerning your question
- an interpretation of your results using the concept of homeostasis
- an evaluation of the strengths and weaknesses of your experimental methods and design, with suggestions for improvement.