BioEd℠

THE SCIENCE OF THE HEART AND CIRCULATION

Activity 3. Why Circulate?

by

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RESOURCES

This publication is available in PDF format at www.nsbri.org and in the Teacher Resources section at www.BioEdOnline.org.

For online presentations of each activity and downloadable slide sets for classroom use, visit www.BioEdOnline.org or www.k8science.org.

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TEAMING WITH BENEFITS

by Jeffrey P. Sutton, M.D., Ph.D., Director, National Space Biomedical Research Institute (NSBRI)

Dr. Jeffrey P. Sutton

Space is a challenging environment for the human body. With long-duration missions, the physical and psychological stresses and risks to astronauts are significant. Finding answers to these health concerns is at the heart of the National Space Biomedical Research Institute's program. In turn, the Institute's research is helping to enhance medical care on Earth.

The NSBRI, a unique partnership between NASA and the academic and industrial communities, is advancing biomedical research with the goal of ensuring a safe and productive long-term human presence in space. By developing new approaches and countermeasures to prevent, minimize and reverse critical risks to health, the Institute plays an essential, enabling role for NASA. The NSBRI bridges the research, technological and clinical expertise of the biomedical community with the scientific, engineering and operational expertise of NASA.

With nearly 60 science, technology and education projects, the NSBRI engages investigators at leading institutions across the nation to conduct goal-directed, peer-reviewed research in a team approach. Key working relationships have been established with end users, including astronauts and flight surgeons at Johnson Space Center, NASA scientists and engineers, other federal agencies, industry and international partners. The value of these collaborations and revolutionary research advances that result from them is enormous and unprecedented, with substantial benefits for both the space program and the American people.

Through our strategic plan, the NSBRI takes a leadership role in countermeasure development and space life sciences education. The results-oriented research and development program is integrated and implemented using focused teams, with scientific and management directives that are innovative and dynamic. An active Board of Directors, External Advisory Council, Board of Scientific Counselors, User Panel, Industry Forum and academic Consortium help guide the Institute in achieving its goals and objectives.

It will become necessary to perform more investigations in the unique environment of space. The vision of using extended exposure to microgravity as a laboratory for discovery and exploration builds upon the legacy of NASA and our quest to push the frontier of human understanding about nature and ourselves.

The NSBRI is maturing in an era of unparalleled scientific and technological advancement and opportunity. We are excited by the challenges confronting us, and by our collective ability to enhance human health and well-being in space, and on Earth.

NSBRI RESEARCH AREAS

CARDIOVASCULAR PROBLEMS

The amount of blood in the body is reduced when astronauts are in microgravity. The heart grows smaller and weaker, which makes astronauts feel dizzy and weak when they return to Earth. Heart failure and diabetes, experienced by many people on Earth, lead to similar problems.

HUMAN FACTORS AND PERFORMANCE

Many factors can impact an astronaut's ability to work well in space or on the lunar surface. NSBRI is studying ways to improve daily living and keep crewmembers healthy, productive and safe during exploration missions. Efforts focus on reducing performance errors, improving nutrition, examining ways to improve sleep and scheduling of work shifts, and studying how specific types of lighting in the craft and habitat can improve alertness and performance.

MUSCLE AND BONE LOSS

When muscles and bones do not have to work against gravity, they weaken and begin to waste away. Special exercises and other strategies to help astronauts' bones and muscles stay strong in space also may help older and bedridden people, who experience similar problems on Earth, as well as people whose work requires intense physical exertion, like firefighters and construction workers.

NEUROBEHAVIORAL AND STRESS FACTORS

To ensure astronaut readiness for spaceflight, preflight prevention programs are being developed to avoid as many risks as possible to individual and group behavioral health during flight and post flight. People on Earth can benefit from relevant assessment tests, monitoring and intervention.

RADIATION EFFECTS AND CANCER

Exploration missions will expose astronauts to greater levels and more varied types of radiation. Radiation exposure can lead to many health problems, including acute effects such as nausea, vomiting, fatigue, skin injury and changes to white blood cell counts and the immune system. Longer-term effects include damage to the eyes, gastrointestinal system, lungs and central nervous system, and increased cancer risk. Learning how to keep astronauts safe from radiation may improve cancer treatments for people on Earth.

SENSORIMOTOR AND BALANCE ISSUES

During their first days in space, astronauts can become dizzy and nauseous. Eventually they adjust, but once they return to Earth, they have a hard time walking and standing upright. Finding ways to counteract these effects could benefit millions of Americans with balance disorders.

SMART MEDICAL SYSTEMS AND TECHNOLOGY

Since astronauts on long-duration missions will not be able to return quickly to Earth, new methods of remote medical diagnosis and treatment are necessary. These systems must be small, low-power, noninvasive and versatile. Portable medical care systems that monitor, diagnose and treat major illness and trauma during flight will have immediate benefits to medical care on Earth.

For current, in-depth information on NSBRI's cutting-edge research and innovative technologies, visit www.nsbri.org.

OVERVIEW

Students will observe the dispersion of a drop of food coloring in water, draw conclusions about the movement of dissolved substances, and develop explanations about the importance of organisms' internal transport systems.

ACTIVITY 3

WHY CIRCULATE?

Have you ever made lemonade and forgotten to stir the mixture? The sweetener and flavoring eventually become distributed within the liquid, but the process, called diffusion, takes time. Diffusion is the random movement of molecules or particles in solution. They bounce against each other, generally moving from regions of higher concentration (where there is more of the dissolved substance) to regions of lower concentration (where there is less of the dissolved substance). Eventually, the mixture becomes evenly distributed. This is the process by which the sweetener and lemonade flavoring become dispersed in the water, even if you don't stir the mixture.

Single-celled living organisms rely on diffusion to obtain some of the resources necessary for life and to eliminate wastes. It is not a coincidence that almost all unicellular organisms live in water-based environments, where dissolved nutrients are readily available just outside the cell membrane. Single-celled organisms also can move wastes outside the cell membrane into the surrounding water.

What happens in large organisms, such as humans, that consist of many millions of cells? These organisms' cells are bathed in water, but the cells often are far away from the external environment. Diffusion is not sufficient to provide needed nutrients or to remove waste from distant cells. In addition, most larger, complex organisms carry out important tasks—obtaining nutrients, exchanging gases, removing wastes, etc.—in specialized regions of their bodies (such as the lungs or kidneys in humans). Consequently, most multicellular organisms have specialized systems (such as the circulatory system) to transport nutrients, waste and other materials from one region of the body to another. This activity allows students to investigate the process of diffusion and to consider why many organisms have internal transport systems.

SCIENCE EDUCATION CONTENT STANDARDS*

GRADES 5–8

LIFE SCIENCE

- Living systems at all levels of organization demonstrate the complementary nature of structure and function.
- All organisms are composed of cells—the fundamental unit of life.
- Cells carry on many of the functions needed to sustain life. They take in nutrients, which they use to provide energy for the work that cells do and to make the materials that a cell or an organisms needs.
- The human organism has systems for digestion, respiration, reproduction, circulation, excretion, movement, control and coordination, and for protection from disease.

PHYSICAL SCIENCE

- The motion of an object can be described by its position, direction of motion and speed.

SCIENCE, HEALTH & MATH SKILLS

- Observing
- Graphing
- Interpreting data
- Applying knowledge

* National Research Council. 1996. National Science Education Standards. Washington, D.C., National Academies Press.

AstroBlogs!

Continue the "blog-wall" with an AstroBlog entry written for Activity 3. It's located on page 42.

Solutions in Water

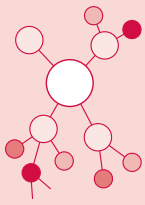
A solution is a uniform (homogeneous) mixture of two or more substances at the molecular level. Many substances dissolve in water because water molecules have a slight positive charge at one end and a slight negative charge at the other. Similarly charged particles of other substances are attracted to and mix with the water molecules, forming a solution.

Brownian Motion

In 1828, the English botanist, Robert Brown, observed that pollen grains suspended in still water jiggle around in a more or less random, zig-zag fashion. Then, in 1905, Albert Einstein published a paper in which he used mathematics to predict that particles much smaller than pollen grains would move in similar, zig-zag patterns. Einstein later would build upon this finding to make his case for the existence of molecules.

According to what is now referred to as Brownian motion, a larger particle in liquid constantly is bumped and jostled on all sides by other, smaller particles. These unequal, random collisions cause suspended particles, even molecules, to move in a non-predictable way.

Update Concept Maps



TIME

10 minutes for setup; 45–60 minutes to conduct activity

MATERIALS

Each group of four students will need:

- 2 sheets of graph paper (0.5-cm grid)
- Graduated cylinder (100-mL or 250-mL)
- Lid or bottom of a Petri dish
- Pencil
- Small dropper bottle of food coloring (red, blue or green; do not use yellow)
- Tape
- Timer, watch or clock
- **Optional:** Digital camera for recording observations

Each student will need:

- Copy of the student sheet (p. 12)

SAFETY

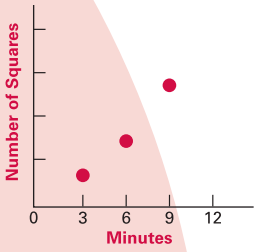
It is a good idea for students to wash their hands with soap and water before and after any science activity. Food coloring may stain hands, clothing and some surfaces. Make sure any spilled water is cleaned up promptly. Follow all district and school safety guidelines.

SETUP & MANAGEMENT

Place all materials in a central location for each group's Materials Manager to collect. Students will work in groups of four.

PROCEDURE

1. Ask students, *Have you ever added sugar to lemonade?* Follow with questions such as, *What did you do after you added the sugar? Was it necessary to stir the mixture? What would happen if you didn't stir the mixture?* Tell students that they will be investigating the movements of a substance when it is dissolved in water.
2. Have Materials Managers pick up the materials listed above for their groups.
3. Students will follow the instructions on their student sheets to observe and record the rate at which a drop of food coloring disperses through the water in a Petri dish. A simple way to measure the area reached by the food coloring is to place the dish over a sheet of graph paper before beginning the investigation. Students will make observations every three minutes (or, you may prefer to have students decide upon the frequency of observations). For each observation, students will count the number of squares in which tint from the food coloring is visible. Students should count only every other partial square, or divide the total number of partial squares by two.
4. Have students graph their results and answer the questions on the student sheet, or record the same information in their lab notebooks. Make certain that students choose an appropriate type of graph for the information being represented (line graphs are generally used for measurements made repeatedly over a continuous period, as in the sample graph (right).



5. Discuss diffusion (the process by which molecules or particles are dispersed randomly through another substance, such as a liquid) with the class. Ask, *Based on your observations, do you think diffusion helps to distribute nutrients from one place to another in the body of a living organism, such as an animal?* [yes] *What are the limitations of diffusion for transporting nutrients and other materials through the body?* [very slow, and only moves from regions of higher to lower concentrations] *How might organisms transport nutrients more quickly?* [with a dedicated transport system, such as the circulatory system in animals]
6. Have students revisit their concept maps and add any new ideas.

ACTIVITY 3
WATER TRANSPORT

How quickly will a concentrated substance spread through water? Think about it. When you add sweetener to a drink, you stir to help the sweetener dissolve evenly. What happens if you don't stir the mixture? This activity will help you find out.

Materials

Lid or bottom of a Petri dish; graduated cylinder (100- or 250-mL); water; two sheets of graph paper (0.5-cm grid); tape; small dropper bottle with food coloring; timer; watch or clock

1. Tape one sheet of graph paper (at the corners) onto a table or countertop. Place the Petri dish on the paper. Using a pencil, trace around the Petri dish to make a circle. Remove the Petri dish and mark the center point of the circle. (Hint: Count the number of squares across the widest part of the circle and mark the center of the middle square.)

2. Measure 35 mL of water into the Petri dish.

3. Carefully place the dish back on the circle you drew on the graph paper.

Investigate

How quickly do you think a drop of food coloring will spread (diffuse) through the water in the Petri dish?

1. Carefully add one drop of food coloring to the center point of the dish.

2. Every three minutes, count the number of squares that have become tinted with food coloring (not all squares will have the same intensity of color). Count only every other partial square, or divide the total number of partial squares by two. Record your numbers in the appropriate box to the right.

3. Record your observations for up to 18 minutes, or until the color is completely diffused through the water in the dish.

Time Interval (minutes)	Number of Squares Tinted
0	
3	
6	
9	
12	
15	
18	

4. Using your second sheet of graph paper, make a graph of your observations. Mark the time (minutes) along the X axis and number of squares tinted by the food coloring along the Y axis.

5. Based on your investigation, answer the following questions. If needed, use the back of this sheet or a separate sheet of paper to record your answers.

   a. Did the food coloring spread completely during your observations?

   b. How could you use your graph to predict how long it would take for the color to spread over the area of the entire dish? What is your estimate?

   c. Is the process you observed (diffusion) an efficient way to spread a substance through water? Explain.

   d. Could an animal rely on the process of diffusion to distribute nutrients from one part of the body to all other parts? Why or why not?

CARDIAC RESEARCH

NSBRI Web site: www.nsbri.org

If one part of a car isn't properly maintained, it can affect the performance of the entire vehicle—especially if it's driven on a long trip. The same can be said for the human body. That's why, when it comes to fitness in space, it's important to create a program for the whole body.

To keep astronauts healthy on long missions, researchers with the National Space Biomedical Research Institute (NSBRI) are developing an exercise program that addresses many of the physical changes caused by microgravity. In one experiment conducted on Earth, participants stayed in a bed tilted at a six-degree angle, with their feet positioned at the higher end of the bed. In this position, the heart works about 15–20% less than it does under normal living conditions. In addition, blood pressure changes and work capacity is lessened. All of these things also happen to astronauts during long-term spaceflights.

The study involved 24 subjects divided into three groups. One group (the control group) stayed in bed and did no exercise. The remaining two groups performed exercise training while in bed. Half of the training subjects received a dietary supplement.

Strength training (rowing, lifting weights) forces muscles to contract enough to briefly interfere with blood flow into muscles. Endurance training exercise (swimming, running and cycling) forces large-muscle groups to contract regularly.

The test subjects exercised using a rowing machine (strength and endurance training in one) with their knees level to their hearts. Subjects also trained with the same regimen athletes use to achieve maximal physical benefit: a program consisting of base training, followed by threshold, interval and recovery training.

The base-training session consisted of moderate rowing exercise performed at a level where subjects could still carry on a conversation, but with slight shortness of breath. With threshold training (one to two days per week), subjects worked at their maximum sustainable effort. For example, at this level, professional marathon runners run hard, but do not sprint.

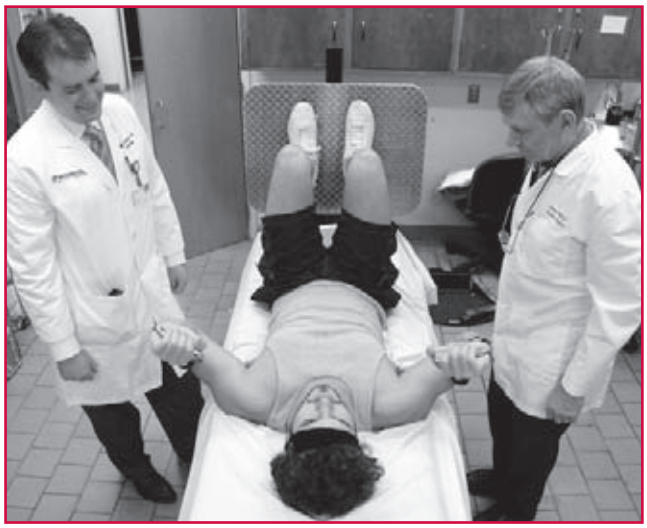


Photo courtesy of UT Southwestern Medical Center at Dallas.

To preserve astronaut health on long missions, scientists are researching the benefits of an exercise program to counteract space-related heart, lung, muscle and bone problems.

The interval-training segment was a high-intensity exercise effort in which subjects pushed their hardest for one to three minutes, building power and explosive energy. Each interval training session was followed by a recovery session, during which subjects exercised at low intensity. The regimen included one long, slow distance effort. Scientists found that this kind of exercise routine preserved heart size and function, muscle size and bone strength.

Researchers now are developing a single exercise routine for astronauts that will prevent damage to their cardiovascular systems, bones and muscles. On Earth, doctors already are using this type of exercise regimen with patients, and are seeing very satisfying results.

The NSBRI, funded by NASA, is a consortium of institutions studying the health risks related to long-duration spaceflight. The Institute's science, technology and education projects take place at more than 60 institutions across the U.S.

An Astronaut's Point of View

AstroBlogs

Create a "blog-wall" in your classroom to stimulate students' thinking and encourage students to express their ideas in writing. Periodically, post a copy of one of the AstroBlog entries below to spark students' interest. Suggested use with specific activities is noted with each entry.

Activity 2

AstroBlogs

The human circulatory system is very well adapted to work under normal Earth gravity. In fact, some parts of the circulatory system count on gravity to help move blood through the body. When I'm floating in space, where humans hardly feel the effects of gravity, my circulatory system faces some real challenges. But even in low gravity, my circulatory system still has to accomplish its transportation function. If it doesn't, I (and my fellow humans!) would not be able to survive space travel. In this unit, you'll learn how the circulatory system functions on Earth, and discover some of the challenges we space travelers face when we're in orbit and when we return home. More on that later…

Activity 3

AstroBlogs

The floating food coloring in this activity shows how things float when we are orbiting the Earth. In orbit, we don't feel the effects of gravity. This condition is called microgravity. You may have experienced microgravity conditions momentarily on Earth. For example, if you ever felt like you've floated out of your seat as you reached the top of a roller coaster, you experienced a moment of what some people call "weightlessness." Do you think we actually become weightless in a situation like this one, on the roller coaster?

Activity 4

AstroBlogs

We use lots of pumps in our spacecraft—pumps for water and fluids that drive different mechanical devices. These pumps have to work in microgravity just as they do on Earth. Can a pump really work in microgravity? As long as it doesn't need gravity to operate, yes.

For example, a sump pump, like those used in basements, would have a hard time working in space. It depends on water flowing "downhill" to refill the pump each time. In space, that water would float right where it was! So in microgravity, it is better to have a pump with elastic walls.

Think of a sponge underwater. If you squeeze the sponge and let it go, it will refill with water, due to the negative pressure left when the elastic sponge walls return to their original shape. The water is drawn into these spaces because the water pressure outside the sponge is greater than the pressure in the empty spaces inside.

Our hearts work in a similar way. The strong, elastic walls of our hearts are like the sponge. After they contract and push blood into the next chamber or arteries, they spring back to their original shape so the chamber can refill with blood. Therefore, my human heart pump works just fine while I'm floating in space. Whew! That's a relief!

An Astronaut's Point of View

AstroBlogs

Activity 6

AstroBlogs

As you can see, the heart is a powerful pump. But like any pump, it can malfunction, sometimes because of our choices for exercise and diet. What about when we are floating in space? Does microgravity affect the heart muscle? Yes!

If you think about it, a lot of the work done by the cardiovascular system involves moving blood upward against gravity. For example, your heart has to push blood more than a foot upward to your brain. If you've ever sucked soda up a super-long straw, you know it takes some work to move liquid against gravity through a narrow tube.

Due to the downward pull of gravity, our blood tends to pool in the lower half of our bodies. While I float in the space shuttle as it orbits the Earth, the blood in my body is not being pulled by gravity toward my feet. Because, of course, there is very little gravity in space! Therefore, more blood than usual will stay in the upper half of my body, and less will stay in the lower half. After just one day in space, my legs start to look skinny and my face starts to look puffy. My nose and ears feel stuffy, too… not fun! It's no surprise that while I'm floating in space, my body doesn't have to use its muscles to hold me upright against the Earth's gravity. This makes my heart rather lazy. It slows down and doesn't have to work as hard to pump blood to the different parts of my body. And we all know what happens to muscles when we don't work them, right? They get weaker and smaller.

*This can happen to an astronaut's heart, too. How do we avoid this? The same way we do on Earth: exercise, and lots of it! We have treadmills and stationary bikes in space to keep our skinny chicken legs and our hearts strong. When I get back to Earth, I'll feel a little dizzy and weak-kneed for a while. But my body will readjust to Earth's gravity pretty quickly and my heart will get strong again. The recovery time happens even faster if I keep exercising. Gotta go… Time to ride the bike!**

* www.esa.int/esaHS/ESAGO90VMOC_astronauts_0.html

Activity 7

AstroBlogs

It's another beautiful day in space! I just finished my lunch. Did you know that we eat tortillas instead of sliced bread up here? Why? Well, if you drop a few crumbs on Earth, they just fall to the floor. If I drop a few crumbs in space, they float around the spacecraft and get in everyone's noses or eyes, or worse, into the machinery. Not cool. But tortillas don't crumble. And besides, I like them with my fajitas, with lots of hot sauce to get my blood moving.

Speaking of blood, did you know that even my blood will change while I'm floating in microgravity? Yep! I get a little dehydrated up here. In fact, my blood plasma volume will drop as much as 20% during a space mission. Then my body reduces my red blood cells so my blood isn't too "thick." We have to work hard to keep hydrated. Luckily, our bodies will return to normal after we're back on Earth for a while. I can eat crumbly potato chips then, too!*

* www.esa.int/esaHS/ESAGO90VMOC_astronauts_0.html. Note: Another resource is Donald E. Watenpaugh. Fluid Volume Control During Short-term Spaceflight and Implications for Human Performance. *J. Exp. Biol.* 2001 204: 3209-32.

AN ASTRONAUT'S POINT OF VIEW
AstroBlogs

Activity 8

AstroBlogs

Exercise! You can't imagine how important it is to those of us who travel through space. We don't just exercise for a half hour or an hour. Sometimes we exercise several hours a day! Why so much?

Well, first, we need to keep strong. Floating around inside the shuttle is easy, but working outside, in a pressurized suit with tools, is really hard. You have to be fit to do this kind of work. More important, exercise helps to slow down, or even reverse, some of the changes that microgravity causes in my circulatory system. Exercise even helps to relieve the stuffy head I get when extra blood collects in the upper part of my body.*

When astronauts exercise, we often collect information about our heart and breathing rates, our muscle mass and our strength. That data is really important for planning long-term spaceflights. Speaking of which, did you know we are working towards launching the first human mission to Mars? That trip will last more than two years. We need to know how to exercise in space, so that we don't end up being Martian couch potatoes when we get there!

* www.esa.int/esaHS/ESAGO90VMOC_astronauts_0.html

Activity 9

AstroBlogs

Blood pressure is an important issue for astronauts, especially during take off and landing. When we blast off from Earth, our hearts have to push the blood against Earth's gravity. Then, as we move into orbit and the microgravity of space, our bodies' control systems tell the circulatory system to adjust. This causes our blood pressure to drop.

When we return home, we have a bigger problem. As we approach Earth, the pull of gravity increases. This makes the heart work harder to move the blood to all parts of the body, including the brain. If the heart doesn't respond quickly enough, we can get light headed, and even faint. Not cool, especially when you're flying a spacecraft at several thousand miles per hour!

Not all astronauts get light headed during reentry, and it's hard to predict who will react this way. I hope that when we land from this mission, I will be clear-headed all the way down. I'm not flying the shuttle, but I want to see the whole landing process. Besides, if I pass out, I might drool inside my helmet. That would be embarrassing!