Re-Engineering the Circulatory System

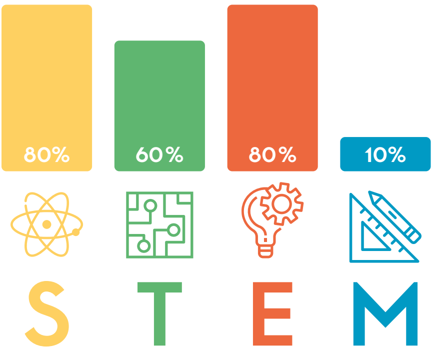
Subjects
Health · Biology

Topics
Systems and system models · structure and function

Key Words
Model · pressure · fluid motion · cause and effect · scale · proportion · quantity

Connection to SDG

STEM Chart



Time for Activity

60 minutes

Introduction

While designing and constructing solutions to problems is at the heart of engineering, in biology, many of the “problems” or challenges in living systems have been solved through evolution. By designing and constructing a circulatory system, you can identify the challenges of moving fluid to and from different parts of the body, identify possible solutions, and develop an understanding of the relationship between structure and function.

Models have inherent limitations, and no model is going to behave identically to a true circulatory system. The power of this activity is in evaluating the model and how design elements link to the actual circulatory system. Below are some common design strategies that can offer some insight into this design challenge.

Key Objectives

1. Engineering isn’t just about physics; it’s part of life sciences, too! Using simple materials, you can design, build and test your own system, and then figure out how to make it better.

Guiding Questions

1. Think about the parts of the human circulatory system.
2. Where does blood need to flow?
3. How does it get there?

Materials/Preparation

1. Butcher paper
2. Permanent marker
3. Pitcher for water
4. Water
5. Food coloring
6. Waterproof construction materials, including those that water can flow through, such as various sizes of rubber or vinyl tubing (surgical tubing, aquarium tubing, etc.), straws, rubber and nitrile gloves, balloons, plastic baggies, water bottles, rubber bands, and so on

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7. Scissors
8. Duct tape
9. Wash basin
10. Funnel
11. Squeegee
12. Towels
13. Optional: laminator, waterproof tape

Fig 1

Tasks/Procedure

1. Use a marker to trace or draw an outline of a 3- or 4-foot-tall human body on butcher paper (see photo below). If you can, laminate the poster. (If your laminator can only handle a maximum width of 2 feet, split the paper in half lengthwise, laminate each half, and tape them back together using waterproof tape.)

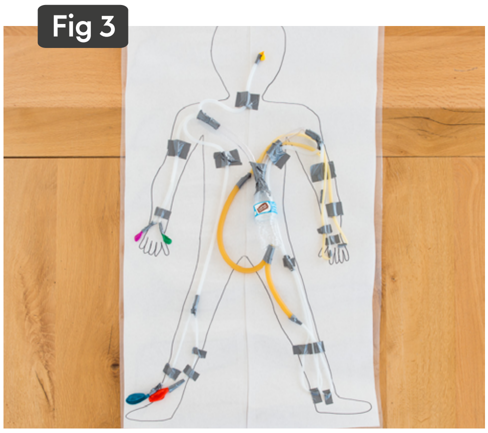
Fig 2

2. Fill a pitcher with water, and add some food coloring to make it easier to see.

Use the waterproof construction materials you've gathered, along with scissors and tape, to design and construct a pump device that will move the colored water through a "circulatory system" constructed on top of the butcher-paper body. Set up the system as best you can to model how fluid would flow through physical space.

If you create a "circulatory system" that has open ends, be sure to include a basin to catch any water that gets pumped out (see photo below). Use the squeegee and towels to clean up any water that leaks.

Fig 3



As you work, make sure that the following are true of your design:

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1. There's a pumping device that can continually move fluid throughout the body.
2. Fluid travels through the "lungs."
3. Fluid flows through the majority of the body.
4. The majority of the fluid does not leak out.

When you have a setup in place, use a funnel to pour the colored water into the "vessels" or the pump you've created until little air remains in the system.

Try pumping the water so it moves through your system. What do you notice?

Fig 4

How far does the water make it around the system with a single pump? Is there a way to make it stronger?

Does it reach every part of the body? If not, what would improve your ability to reach those parts?

In your design, does the water move in one direction or does it move back and forth? What would happen if blood in the human body moved in both directions? What are some possible solutions?

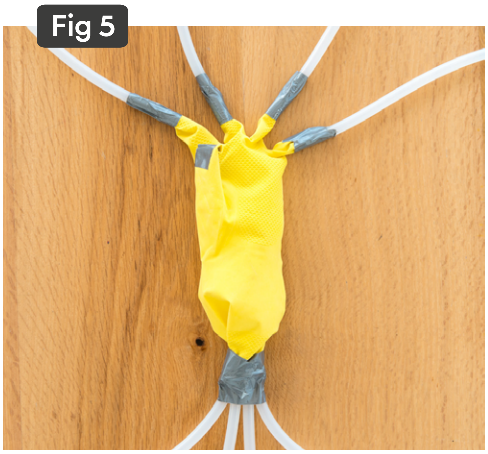
If you test your system while it's laying down horizontally, you eliminate the effects of gravity. What problems would your system encounter if gravity were a factor? How might you solve them?

Now try to redesign your system using what you've learned. What worked better in your redesign?

Fostering Discussions

Modeling the Heart

Fig 5



In your model, the pumping device you create represents the human heart. The most common "hearts" people tend to construct are single chambers—either a water bottle with vessels entering either side, or a balloon or glove with vessels entering the openings.

In both cases, the fluid flows in a back-and forth-motion, and there's not enough pressure to maintain fluid flow throughout the system. When the heart is squeezed, the fluid moves outward; when it's released, the fluid moves back into the heart.

This back-and-forth motion would create a significant problem for the body because the blood needs to move in a clear, unidirectional path in order to retrieve new ma-

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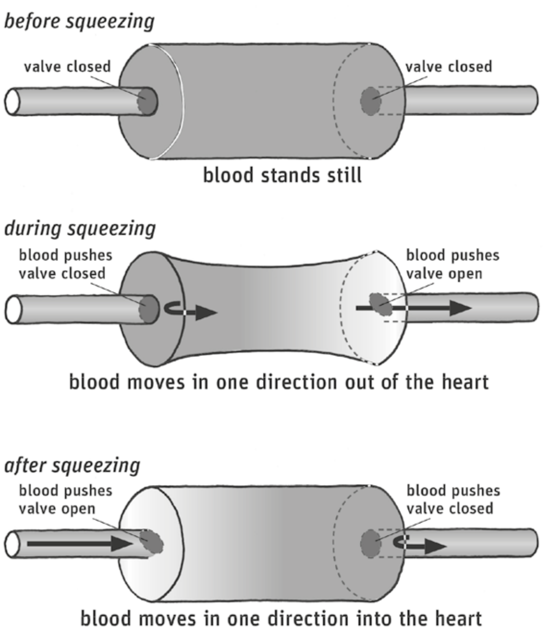
terials and deliver them to the cells and to remove waste products from the cells. Otherwise, the same blood carrying the same materials will keep reaching the same cells.

In a real human heart, there are four one-way valves that prevent the blood pushed out during a contraction from flowing back into the heart after the heart relaxes. The diagram below shows a simplified version of how valves prevent backflow.

Can you design a new and creative way to prevent backflow in your engineered heart?

Fig 6

Heart with valves added



Modeling the blood vessels

There are three main types of blood vessels: arteries, veins, and capillaries. Each has a structure that is closely related to its function. Most people will have used tubing to represent blood vessels in their models.

Arteries

Arteries carry blood from the heart to the lungs, and on to the cells of the body. People often use thick-walled, wide tubing to create the bulk of their model's circulatory system. Because the arteries carry blood away from the heart, their walls are thick and withstand the high pressure. While the quantity of blood carried by this vessel is great, you may notice that the tubing is not sufficiently flexible, and would not actually be able to come into contact with individual cells.

Veins

Veins carry blood from the cells of the body back to the heart or the lungs. Because the pressure in your engineered system is relatively low, you may not have chosen to distinguish between the structures of arteries and veins in your design. In reality, vein walls are thinner than arterial walls; they do not need to withstand the high blood pressure that arteries do.

Sometimes, people who find they have significant backflow in their model's veins add more pumps to make up for the loss in pressure. Think about the benefits and disadvantages of those extra pumps as you reengineer your model. To prevent a backflow of blood, many of the veins of the body are equipped with one-way valves that work much like those in the heart. See photos below for examples of how you might add this to your model.

You may also have chosen to manually force the blood upwards with your hands. In the human body, skeletal muscles such as those in your legs do some of that work. Because the majority of veins are moving blood from parts of the body that lie below the heart, they're not only fighting low pressure due to the slowdown of blood in the capillaries, they're also working against gravity.

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Fig 7

Capillaries

You might have used the smallest tubing to reach the extremities, but found that it wasn't small enough, or flexible enough, to reach all the cells. Capillaries cannot be easily modeled with ordinary materials. Because real capillaries are approximately the width of a human hair, they allow only a single-file line of red blood cells to pass at any given time.

It's estimated that there are up to 60,000 miles of blood vessels in the human body, most of which are capillaries. Because the sheer number of capillaries and the blood volume they contain is so large, the overall pressure is very low, and the blood moves very slowly. Capillaries surround the cells and allow small molecules such as carbon dioxide, oxygen, water, glucose, and nutrients to be exchanged between the blood and the cells.

Safety

Vinyl tubing can be expensive in large quantities. One alternative is using straws for the bulk of the blood vessels. Though this limits the variety of blood-vessel diameters, a minimal amount of large tubing is enough to see a significant difference in fluid flow.

Store materials in plastic bins. Prepare "refill" supplies (fresh towels, replacement gloves, balloons, and straws, plus a small amount of extra tubing) in an accessible place so students can restock bins at cleanup time for the next class.

Place water buckets near each table if sink access is limited.

When cleaning up, have students remove as much tape as possible from the tubing. Cut off remaining tape with scissors.

Possible Extensions

In the classroom, it can be helpful to frame this challenge based on student knowledge and class curriculum. For example, if students have studied other body systems, you might pose questions about how various parts work together to perform a unified a function. If they've studied cellular respiration, the questions you pose might focus on the materials that must be delivered to and removed from the cells, and why this is essential. If students have recently studied pressure, they can review the phenomena that affect the pressure of fluids.

Once you've developed an entry point, pose the challenge: Design and build a pump device that will squirt water through a "circulatory system" using what you have learned about ______________. Introduce the materials,

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state how the system will be deemed effective, and how you will evaluate student work. You can also have students develop these criteria themselves.

Considering design and construction

During this phase, students may choose to add "blood" to their systems at different points in the design to see how well given aspects of the system are working. Much of the design will develop as students determine how well supplies work for a given purpose, so significant iteration is embedded in this process. Students will most likely need help connecting the tubing. You may want to drill appropriately sized holes in the large tubing while the tubing is dry so students can easily make connections between large and small tubing.

Distribute materials early so students have plenty of time to work with them, but have each group agree upon and sketch a model of their system before they begin construction. Encourage students to keep improving their systems as they learn, but be sure they sketch out a final version before completing the task. Make sure students are clear about what will be needed by other classes so materials are not inadvertently destroyed.

Analyzing data and evaluating models

Watch students work to gain a sense of how they're thinking about the science and engineering practices inherent in this challenge. By listening to their questions and asking about their design choices, you can gain insight into how students are approaching the task and thinking about the circulatory system. Challenge students in each group to test their systems under varying conditions (for example, ask them to think about how well a system would work during exercise or sleep, when heart rate changes).

Have students explain how their systems work to their classmates. They should be able to defend the strengths of their systems as well as discuss the weaknesses and negative impacts they would have on the body.

Have students identify the patterns in different solutions. Features to focus on might include fluid flow in different-sized vessels, the type or size of effective pumps, changes in pressure throughout the system, prevention of backflow, issues around fluid not making it back to the heart, and dealing with leaky vessels.

After students have evaluated their initial designs, have them decide which design aspects they might want to incorporate into their next iterations. Ask students to defend their choices based on evidence from the first test, and explain why these aspects are important based on their current understanding of the circulatory system.

Authors/Source

This activity was inspired by the Pump it Up! Design Challenge from the Tech Museum in San Jose, CA.

Moyer, Richard, and Susan Everett. Everyday Engineering: Putting the E in STEM Teaching and Learning. Arlington: NSTA Press, 2012. This book demonstrates ways various ways to integrate engineering into your science curriculum.

Allison, Linda. Blood and Guts. Boston: Little, Brown, 1976. This book has clear, simple explanations about organs and organ systems and offers ways to actively involve students in earning more about the human body.

Exploratorium Teacher Institute
https://www.exploratorium.edu/snacks/re-engineering-circulatory-system