

Working

Building artificial hearts to learn about circulatory system physiology

David Brock

Vertebrate anatomy and physiology—as guides to the structure and function of the human body—seem to capture student interest like no other topic in the life sciences. In my experience, students are fascinated by the circulatory system—especially the heart. It is no wonder why: Until modern medicine discovered how to make it start again, a beating heart literally defined the line between life and death.

Despite student interest, the heart is often a poorly understood topic in biology. Students are usually able to memorize its anatomical information and report the sequence of events in a contraction. However, if asked to explain the heart's role in the body in their own words (a reasonable analysis question) or why injuring it weakens a person (a good synthesis problem), students can seldom do more than parrot back words such as *sinoatrial node*, which reveals a lack of true understanding. In short, students often do not understand the physiology—or function—of the heart.

To help students understand this vital organ's physiology, I created an investigation activity involving the mammalian heart and its role in the circulatory system. Students design, build, and demonstrate working artificial “hearts” to exhibit what they know about the circulatory system. These physiological models provide a great opportunity to test for hidden misconceptions and illustrate other essential concepts students need to learn about circulation (e.g., blood pressure and the path blood takes). This article describes how to incorporate the model heart activity into the classroom, including material that can be taught using the working product.

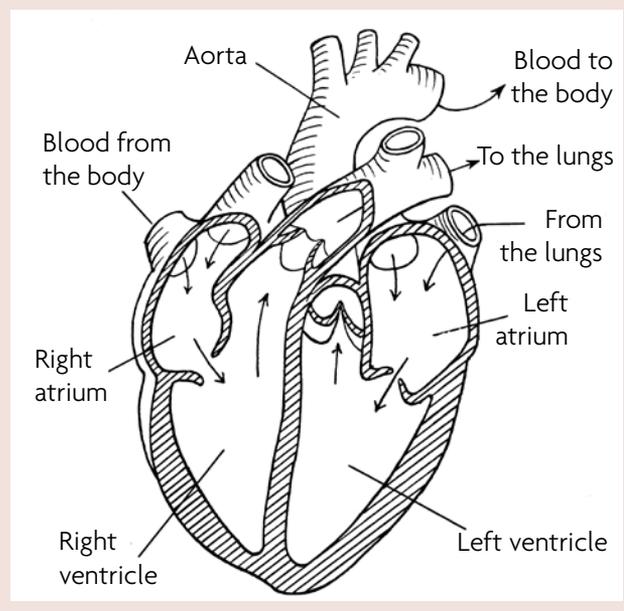
Relation to the Standards

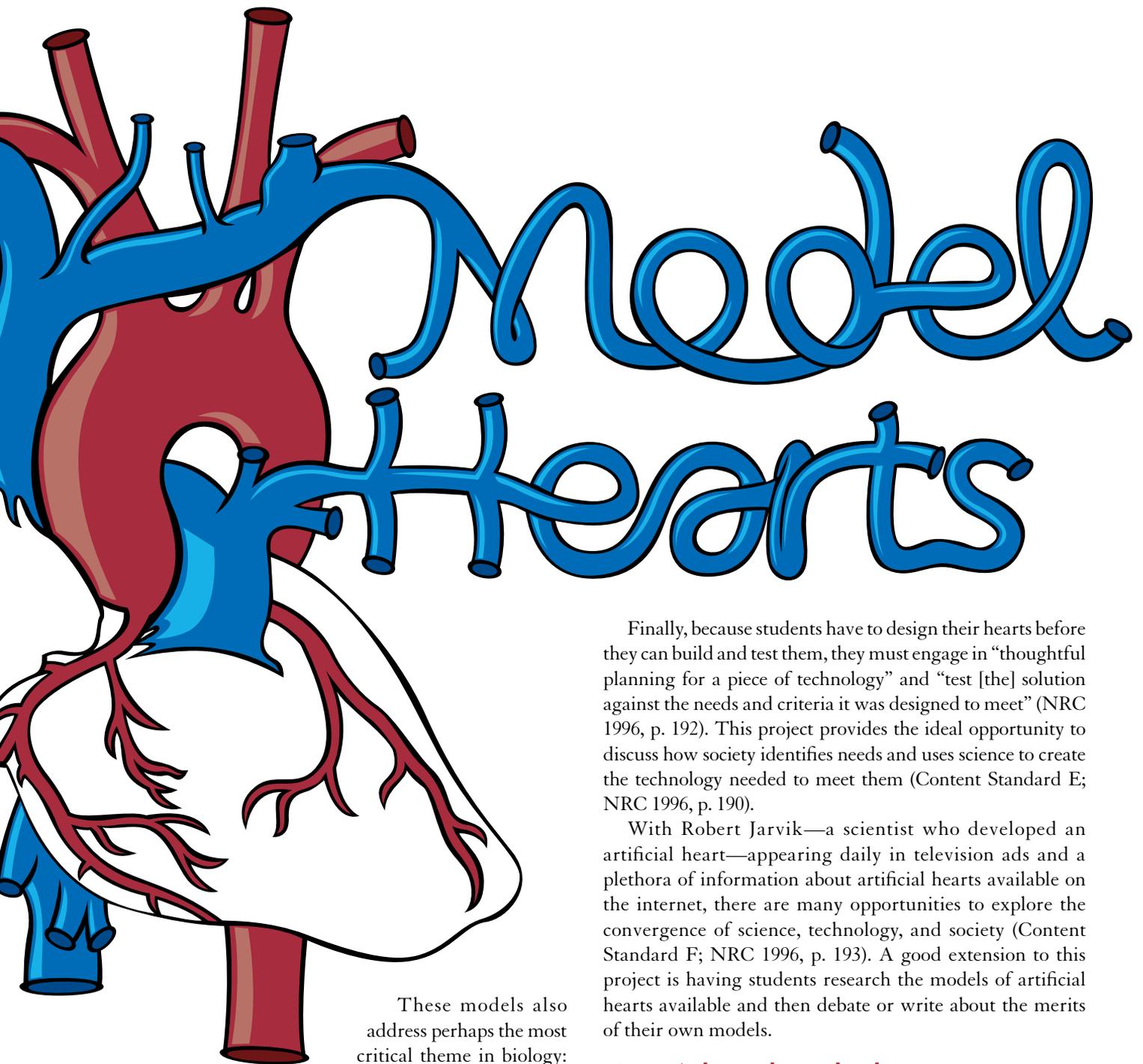
Studying anatomy and physiology provides a general introduction to scientific investigation. The working hearts

described in this article provide a way to teach and evaluate basic problem-solving skills “that support the development of student understanding [of the character of scientific inquiry] and nurture a community of science learners” (NRC 1996, p. 31). Because the activity requires students to work in small groups, it generates the kind of discourse that enables them to experience “science as a human endeavor” (NRC 1996, p. 200). Perhaps the most significant National Science Education Standard addressed is developing in students the abilities, understanding, and perspective necessary to engage in authentic scientific thinking (NRC 1996, p. 173).

FIGURE 1

Diagram of the heart.





These models also address perhaps the most critical theme in biology: the relationship between structure and function, and the direct dependency of the latter on the former at all levels of organization—from the molecular to the ecological (Content Standard C; NRC 1996, p. 181). The artificial heart activity provides a concrete opportunity to teach this central life science idea. For example, students can understand why the larger size of the ventricles generates the larger force of the systolic blood pressure because they can literally feel how much firmer the plastic tubing gets when the extra “blood” is forced into it by the larger pumping action of the model’s ventricles.

Finally, because students have to design their hearts before they can build and test them, they must engage in “thoughtful planning for a piece of technology” and “test [the] solution against the needs and criteria it was designed to meet” (NRC 1996, p. 192). This project provides the ideal opportunity to discuss how society identifies needs and uses science to create the technology needed to meet them (Content Standard E; NRC 1996, p. 190).

With Robert Jarvik—a scientist who developed an artificial heart—appearing daily in television ads and a plethora of information about artificial hearts available on the internet, there are many opportunities to explore the convergence of science, technology, and society (Content Standard F; NRC 1996, p. 193). A good extension to this project is having students research the models of artificial hearts available and then debate or write about the merits of their own models.

Materials and methods

Before developing models, students first need to become familiar with the anatomy of the heart (see “Author’s note,” p. 38, and Figure 1). Once students have done this, have them build a working model of the human heart. Because this is a physiology activity and not an anatomy lesson, students’ hearts do not have to look like actual mammalian hearts. However—because function is dependent on structure—each heart must meet the following criteria:

- ♦ Each vital structure must be present in some fashion (i.e., two atria, two ventricles).

- ◆ All structures must be properly linked to one another according to their physiological relationship (e.g., the ventricles should not be able to pass fluid directly between each other).
- ◆ Each heart must enclose a self-contained, sealed, and contiguous water solution (i.e., the “blood”), so that no “transfusions” are needed and no “bleeding” occurs during the heart’s operation.
- ◆ The heart must actually be able to move fluid but does not have to function autonomously (i.e., students may produce the necessary forces).
- ◆ Everything (i.e., valves, contractions) must work in its proper order and manner when the model is operated.

Once students understand the criteria, provide the necessary materials to groups of three or four students and give them space to be creative. Because students design their own models, the materials needed vary. I typically provide students with the materials listed below but allow them to suggest additional materials (e.g., food coloring):

- ◆ four vinyl examination gloves (or plastic water bottles, or balloons, or equivalent) (Safety note:  CAUTION Because of the potential for latex allergies, use only vinyl examination gloves.)
- ◆ 1–2 m of 5/16 in. vinyl or plastic tubing
- ◆ one tube of silicon aquarium sealant, cement, or bath caulk
- ◆ pinch cock (or other form of simple clamp)
- ◆ water (to simulate blood)

Students have two 70-minute classes to complete the activity. During that time, they brainstorm how to solve the problem, develop their solutions into a workable design, and build and demonstrate their models. Taking two days to complete the activity allows you to acquire and provide any unanticipated materials that students may suggest. For example, I have had students ask for marbles in an attempt to mimic how artificial replacement valves work, and for different widths of plastic tubing to simulate the different arterial diameters in the aorta and pulmonary artery.

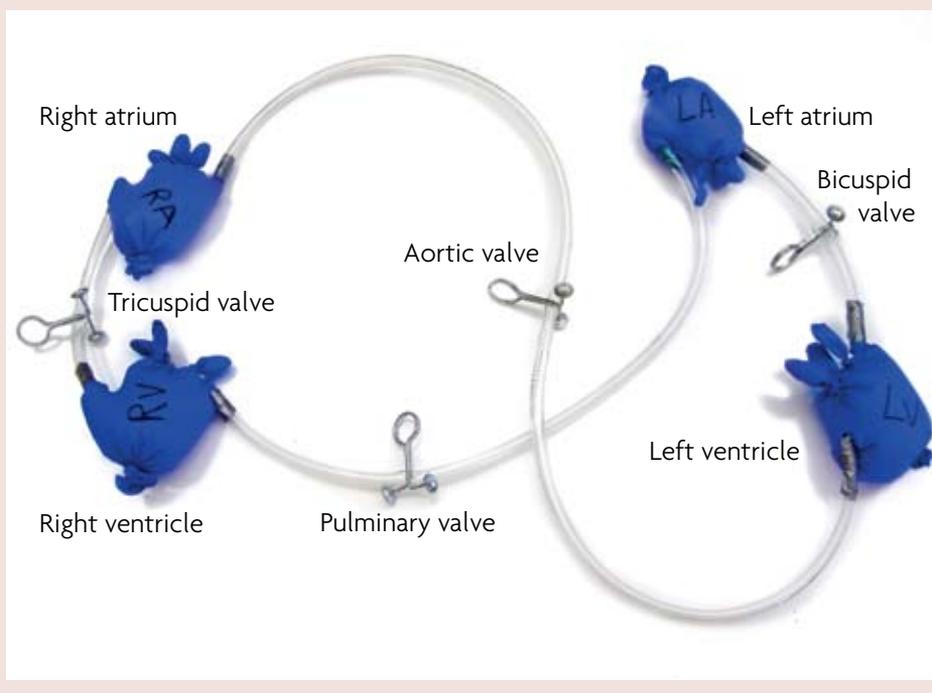
Author’s note.

I sometimes begin the artificial heart project with the dissection of a real heart to increase my students’ familiarity with the organ’s actual structure. Cow hearts have proved to be the most successful because their larger size allows students to explore all of the openings and connections more easily. (Safety note: Given the risk of microbial/viral infection sources, secure only commercially prepared cow hearts.)  CAUTION This kinesthetic learning seems to improve students’ ability to build and demonstrate the workings of their models more effectively. Standard dissection safety cautions apply: Students should be cautioned to wear indirectly vented chemical-splash goggles, aprons, and gloves, and take care with sharp instruments. However, I want to emphasize that having students perform dissections is not a necessary part of the activity. Alternative methods (including simple diagrams such as that in Figure 1, p. 36) quite adequately introduce students to the heart’s basic anatomy, and I have used these alternatives equally successfully in my own classes.

FIGURE 2

Photo of a correctly finished heart model.

In this model heart, each glove represents a specific chamber of the heart. Tubing lengths are relative to the distance blood would actually have to travel between the various chambers, and the clamps represent the various valve structures that guide the direction of the blood’s flow.



Some students have trouble getting past the literal anatomy of the heart and may glue glove chambers directly to each other until you ask: “How are you going to separate the flow so that the blood does not mix?” Others forget to leave an (easily closed) opening to fill their hearts with blood (e.g., a cut glove finger that can be knotted). Some will assemble the various parts correctly, only to tape, rather than glue, seams shut—their system will “bleed” until you remind them that even an opening as narrow as a paper cut bleeds until clotting completely cements the gap.

With teacher guidance, most students find their way to a solution that looks similar to the heart in Figure 2. Ideally, the heart should have short, roughly equal pieces of tubing between the right atrium and right ventricle and between the left atrium and left ventricle. There should be significantly

longer pieces of tubing between the right ventricle and left atrium and between the left ventricle and right atrium to reflect the longer pathways the blood must take between these chambers; the tube between the left and right atria should be the longest.

There must be valves in place between each chamber to guide the direction of blood flow when the heart is operated.

Ultimately, students make their own choices and the final design will be somewhat unique. The structure of the model does not have to reflect exact anatomy, but it must support proper functioning of the artificial heart. The basic activity takes two days; if you include the possible extension activities described in “Discussions and extensions” (p. 40) the project will take about a week.



Keywords: Heart
at www.scilinks.org
Enter code: TST120901

FIGURE 3

Assessment rubric.

Structural components (50%):

- ◆ four chambers (4%)
- ◆ atria chambers same size (4%)
- ◆ ventricle chambers larger than atria chambers and different in size (medium and large) (6%)
- ◆ four valves (4%)
- ◆ four lengths of tubing (12%)
 - ▶ two short
 - ▶ one medium
 - ▶ one long
- ◆ correct arrangement of chambers, tubing, and valves (16%)
 - ▶ small-size right atrium attached to medium-size right ventricle by short tube with valve between them
 - ▶ small-size left atrium attached to large-size right ventricle by short tube with valve between them
 - ▶ right ventricle attached to left atrium by medium tube with valve between them
 - ▶ left ventricle attached to right atrium by long tube with valve between them
- ◆ water (4%)

Functional components (50%):

- ◆ students squeeze both atria simultaneously (8%)
- ◆ students open both valves between the atria and the ventricles before squeezing the atria (8%)
- ◆ students squeeze both ventricles simultaneously (8%)
- ◆ students open both valves between the ventricles and the atria before squeezing the ventricles (8%)
- ◆ valves work to cause water to flow in correct direction (9%)
- ◆ system does not leak (9%)

Assessment

This is primarily a physiology assignment, not an anatomy lesson. When evaluating student models, it is critical to focus more on how the heart model works, and less on how it looks. For example, when you are assessing the models, do not base the evaluation on atria chambers being directly above ventricles or on a physically replicated septum.

Students do not need to create a biological representation of the body or lungs. From a physiological standpoint, the heart is a closed system that pumps blood to itself: The body and lungs are simply very large networks of tubes connecting the pumps to one another. Therefore, as long as the fluid in a student model moves in the same defined pattern that is found in the real human circulatory system, it is not essential for the heart to display all of the anatomical relationships. If students avoid the common error of first squeezing the

Safety considerations.



The materials students use to construct the hearts can vary; therefore, so can the safety concerns. Students should use vinyl gloves, standard plastic tubing, and silicon cement as suggested in “Materials and methods,” (p. 37). Either cut the lengths of plastic tubing ahead of time or have students use scissors (rather than a knife) to reduce risk of injury. In addition to indirectly vented chemical-splash goggles, students should wear aprons and protective gloves during model construction to prevent the silicon cement from directly touching their skin (prolonged exposure can produce a mild chemical burn). Secure and review the Material Safety Data Sheet (MSDS) for sealant or caulk, and make sure ventilation can accommodate fumes. Have students work on a tarp or shrink wrap so that any sealant can be wrapped up and thrown away. After about 24 hours, the models are typically dried and cured and are safe to touch with bare hands.

right atrium followed by the right ventricle, and then the left atrium followed by the left ventricle—but instead correctly contract both atria followed by both ventricles—they should receive full credit for that portion of the assessment.

Finished hearts, however, must have some structural requirements, specifically:

- ◆ The four chambers should be connected properly with appropriate tubing lengths to represent the physiological demands of moving the blood different distances.
- ◆ The chambers should be different sizes to represent the difference in force they can generate to move the blood different distances.
- ◆ The chambers should be separated by the correct valves.
- ◆ The link between the right atrium and left ventricle and the link between the left atrium and right ventricle must cross over as they do in a living system (Figure 2, p. 38).

In addition, the completed system should be fully closed and watertight with no (or minimal) leaks—students should not have to transfuse water at any stage of their demonstration.

As for physiology requirements, when students demonstrate how their hearts work, it is critical that they remember to contract both atria simultaneously (Figure 2; the two gloves labeled “RA” and “LA”) while opening only the valves between the corresponding atria and ventricles (Figure 2; the clamps between gloves RA and RV and between gloves LA and LV). Then, students should squeeze both ventricles simultaneously (Figure 2; the two gloves labeled “RV” and “LV”) while closing the first set of valves and opening the second two (Figure 2; the clamps between gloves RV and LA and between gloves LV and RA).

The key is to replicate the contraction so the chambers react as they would in a real heart—both atria and then both ventricles—and to manipulate the valves so that the liquid flows in only one direction (from atria to ventricles to atria) without any backflow. I have watched many groups with otherwise picture-perfect hearts either move their fluid only one chamber at a time or squeeze blood from one atrium into two ventricles. Therefore, when observing model presentations, make sure the chambers are operated together and that the correct valves are opened in pairs. For further information on assessing this activity, see the sample rubric in Figure 3 (p. 39).

Discussion and extensions

The primary goal of this activity is to give students a tangible way to understand the actions of the human circulatory system. Students can see how the heart is essentially a coordinated set of pumps moving liquid one way in a closed loop.

For example, students better comprehend the sophisticated link between sinoatrial and atrioventricular nodes—the two parts of the heart that coordinate the alternating contractions

of the atria and the ventricles—when they have to coordinate which chambers are pumping at a given time. They are also able to understand why the different chambers of the heart are different sizes because they can literally see and feel how much force it takes to move blood between chambers.

From a developmental standpoint, students can understand why the heart forms before any other organ in the mammalian body. The simplified models help students visualize the heart basically pumping to itself, as it does in the first weeks of embryonic growth. The developing body and lungs simply become the increasingly more complex “plumbing” that connects two sets of the heart’s four pumps.

Even the heart’s dysfunctions make more sense when it is possible to observe consequences. Students can simulate damage to one of the model’s pumps (e.g., by gluing it to a rigid surface to decrease its flexibility) and watch what happens to the blood’s flow, or remove a valve to see how the blood travels backwards. These visuals allow students to witness the physiology of disorders and better understand why heart attacks and heart murmurs produce the associated symptoms. Students can observe how damage to certain parts of the heart (e.g., the left ventricle) is more medically significant by simulating different possibilities and seeing the results: Students can investigate the amount of stress plaque deposits in the arteries put on the heart by injecting some glue into the tubing near a chamber.

Once students understand the physiology of the heart, you can give them a problem to solve about the organ and its role in circulation, and encourage them to hypothesize and test possible answers. From healthy physiology to bleeding, clotting, aneurisms, strokes, bypass surgery, and more, providing students with the opportunity to create functional, artificial hearts allows them to explore endless circulatory-system concepts. ■

David Brock (brockda@rpcs.org) is a science teacher at Roland Park Country School in Baltimore, Maryland.

Reference

National Research Council (NRC). 1996. *National science education standards*. Washington, DC: National Academy Press.

Further resources.

- Campbell, N., and J. Reece. 2008. *Biology*. 8th ed. San Francisco: Benjamin Cummings.
- Hall-Craggs, E.C.B. 1995. *Anatomy as a basis for clinical medicine*. 3rd ed. London: Williams and Wilkins Waverly.
- Public Broadcasting System (PBS). 1999. NOVA online: The electric heart. www.pbs.org/wgbh/nova/eheart
- Shier, D., J. Butler, and R. Lewis. 2003. *Hole’s essentials of human anatomy and physiology*. 8th ed. St. Louis: WCB/McGraw-Hill.