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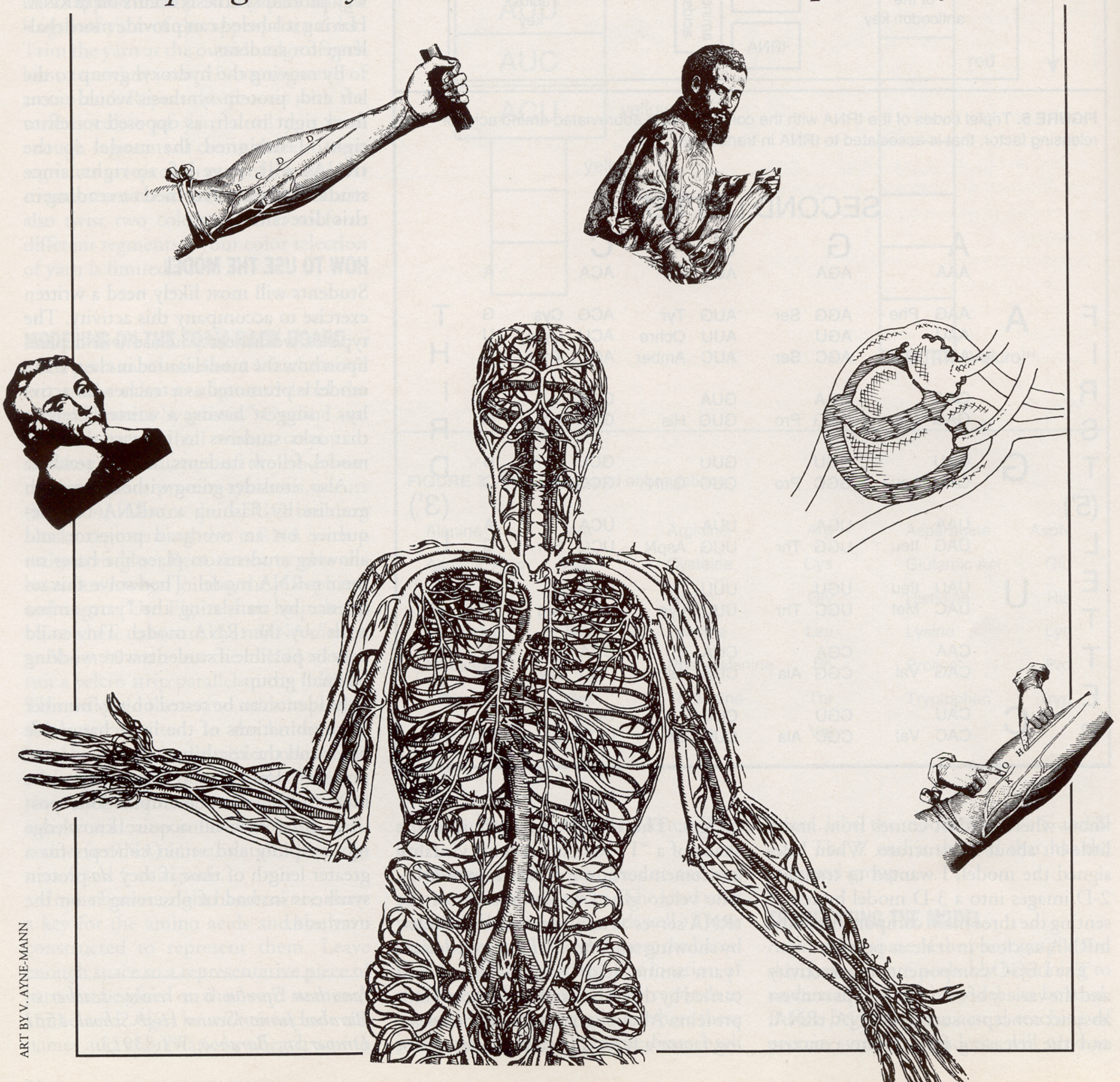
Of Squid Hearts and William Harvey

Corrupting history to teach circulation and the process of science



ART BY V. AYNE-MANN

by Douglas Allchin

In *De motu cordis* ("On the motion of the heart"), published in 1628, William Harvey (Figure 1) presented evidence for the circulation of the blood. This achievement, of course, is now considered a landmark of science, and the concept is one of the central principles we hope to convey in teaching human physiology. Yet today, circulation is so familiar to us that we often forget how difficult a concept it is for our students to conceive of or understand experimentally.

By discretely borrowing from history—that is, by simulating some of Harvey's own work—we may help students to reconstruct the concept on their own (see "The Constructivist Learning Model," *TST*, September 1991). The strategy of the exercise is to provide the pieces of a puzzle in a context of inquiry that will allow students to re-create Harvey's discovery. In addition, by reflecting on the process itself, we can highlight skills in experimental interpretation and creative thinking.

SETTING THE SCENE

One of the critical steps in science is framing the original problem—what John Jungck has aptly called "problem-posing." Before introducing the topic of circulation, therefore, I first try to generate a context for *asking* about the heart and blood system, and how they work. So, at the start of class, I have students record their pulse and breathing rates. Next, I have them perform some vigorous exercises, such as jumping jacks or running around the building. Afterwards, they recheck their pulse and breathing rates and we discuss the causes behind the change. Although few students are surprised by the accelerated rates, most are unable to fully explain why this change takes place.

Students examine the link between increased physical activity and increased blood flow (drawing upon their knowledge of cell metabolism), and their intuitions about the role of the lungs and air. During the discussion, I elicit a variety of views and refrain from "editing" or correcting them. Many of the intuitive misconceptions that surface will be transformed by subsequent investigation and discussion.

Finally, I direct attention to the heart and pose the problem of its function. It "freshens" the blood, most respond. Those who supply the "right" answer are issued a challenge: What reasoning or observational evidence led them to this conclusion? This reinforces the notion that knowing the *why* is as important as knowing the *what.* Conceptual roadblocks should be used to provoke student curiosity and raise questions about how the heart functions. Thus, though the eventual objective is to teach conclusions about circulation, we *begin* by asking about the heart.

We first review what others have already discovered for us. We examine diagrams that summarize other dissections—for example, by the renowned Renaissance anatomist, Vesalius—showing how ves-

FIGURE 1. William Harvey.

FIGURE 2. Blood vessels (Vesalius, 1543)

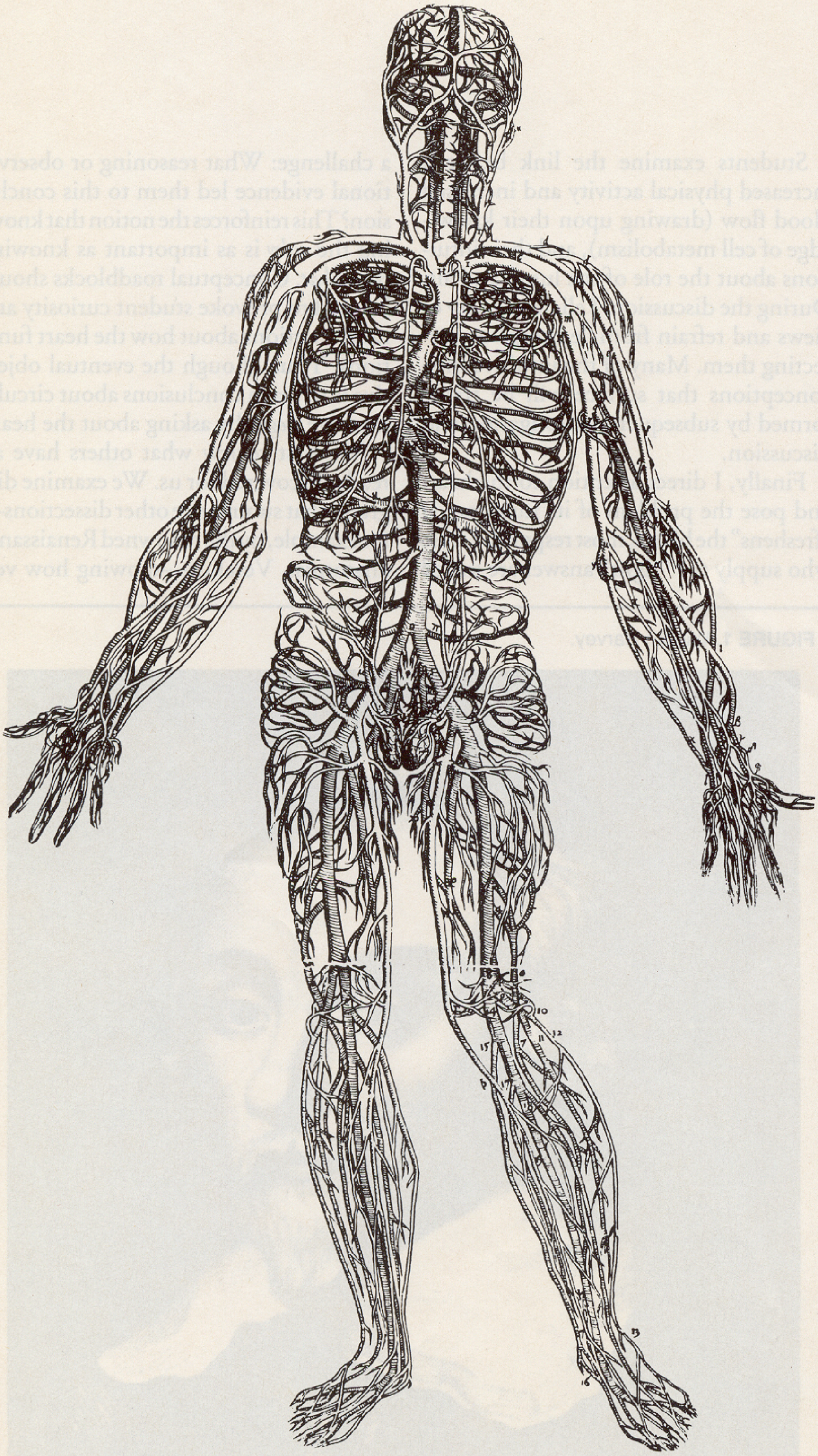
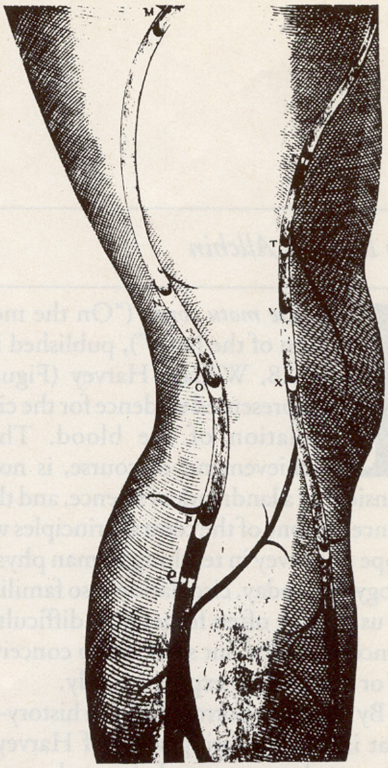


FIGURE 3. Venous valves (Fabreus, 1603).



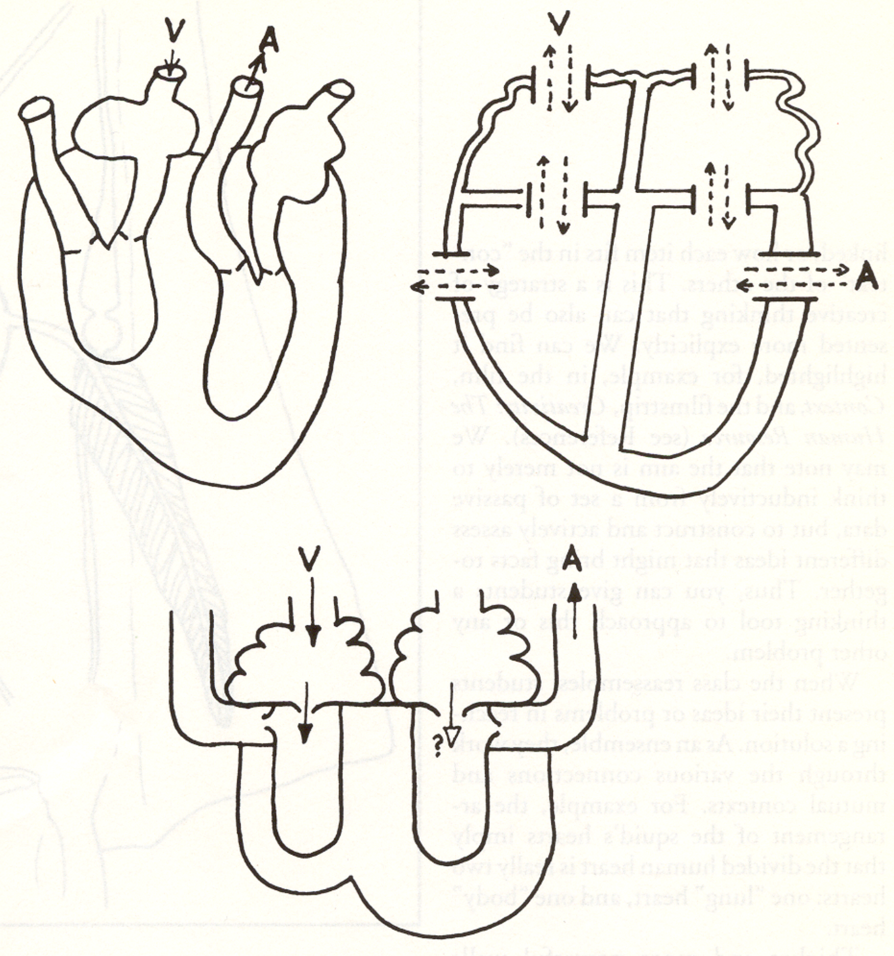
sels branch away from (lead into?) the heart (Figure 2). We note that there are two sets of vessels: some called veins, and some the Greeks called "air ducts," or "arteries" (because they were hollow in the corpses they studied). We also note that some vessels (the veins) have "little doors," or "clacks," and I mention that Fabricus suggested in 1603 that by retarding flow, the clacks prevented blood from collecting in the extremities (Figure 3). These all become puzzles of structure to explain.

INTO THE LAB

Once prepared, student groups dissect sheep hearts to document and interpret their structure. Here, they repeat (unwittingly) the basic observations of Harvey and others before him. Our previous discussions of the relationship between structure and function help students to focus on this "new" structure.

In some cases, I prompt their observations by asking about the character of vessel walls, the thickness of muscle, or the volume of cavities. I might also point to a valve and ask naively, "I wonder

FIGURE 4. Students' functional drawing of the heart.



what that is for?" I also have one sheep pluck prepared as a demonstration, so that they can see how some vessels lead to the lungs. Each group's heart has been pre-labeled to indicate where the blood vessels led to within the body. I also make sure that everyone has seen (and usually been impressed by) a cross-section of the heart and compared the two sides. Functional diagrams are to be completed as homework.

In class the next day, students pool and compare their interpretations (Figure 4). I ask that they think of themselves as a scientific community sharing their findings. Where data is available, I encourage them to calculate an approximate rate of blood flow. Harvey, for example, estimated that the heart holds 2 ounces. At 72 beats per minute (data available from Day #1), 60 minutes per hour, even with only 25 percent replacement each beat, the heart must process 135 pounds of blood each hour.

Students will naturally wonder, "Where does all that blood come from?"

Students will naturally wonder, "Where does all that blood come from?" (I voice this query aloud if left unasked by a student.) The role of two sides of the heart, without any clues, is also often a mystery. I conclude the class with a "new" discovery—one not critical for Harvey, in fact, but one that helps students to perceive the relevant relationships. I present a dissection of a squid and point out that it has *three* hearts. We note how they are positioned with respect to the two gills and body and I provide my contribution: a handout of my own diagram of the squid blood vessels (Figure 5).

Finally, I introduce the students explicitly to Harvey. Once again, I create a "human" context to science by noting several aspects of the period in which Harvey lived (Figure 6) and mentioning that he became King James's physician in 1618. To preface the next activity, I tell students that the year is 1616 and that Harvey has just made another observation. I then lead them through the demonstration documented in the renowned figure from *De motu cordis* (Figure 7, also sometimes reproduced in introductory texts). Each student can evacuate blood from a vein segment in their arm by blocking the vein and drawing the blood towards their body. When a finger is lifted from the far end, the blood returns; but when the near finger is released, the vein remains empty.

MAKING CONNECTIONS

With this final piece to the puzzle, I send students home to make sense of all the information they have collected. This "think-homework" is an explicit exercise in creative thinking, and so I have students record and submit in writing the complete path of their thoughts—including their speculations and dead ends. This is critical: their detailed documentation allows you to analyze and comment on their thinking strategies. You need not identify where the "right" or "wrong" answer was produced. Rather, you can highlight how certain approaches yielded results, or point out where some generalized strategy might have been applied more productively. (See Darden in References for examples of specific thinking strategies in science.)

The thinking task is made more deliberate by diagraming the possible relationships between elements of the students' knowledge (Figure 8). Students are encouraged to "make connections" by imagining how their observations are possibly linked, or how each item fits in the "context" of the others. This is a strategy of creative thinking that can also be presented more explicitly. We can find it highlighted, for example, in the film, *Context,* and the filmstrip, *Creativity: The Human Resource* (see References). We may note that the aim is not merely to think inductively from a set of passive data, but to construct and actively assess different ideas that might bring facts together. Thus, you can give students a thinking tool to approach this or any other problem.

When the class reassembles, students present their ideas or problems in reaching a solution. As an ensemble, they work through the various connections and mutual contexts. For example, the arrangement of the squid's hearts imply that the divided human heart is really two hearts: one "lung" heart, and one "body" heart.

Thicker and more powerful walls clearly identify the body heart. The other half of the heart must pump blood to the lungs—but why? Is blood simply delivered to the lungs? How does respiratory activity relate to leg muscle cells during exercise?

FIGURE 5. Squid circulation.

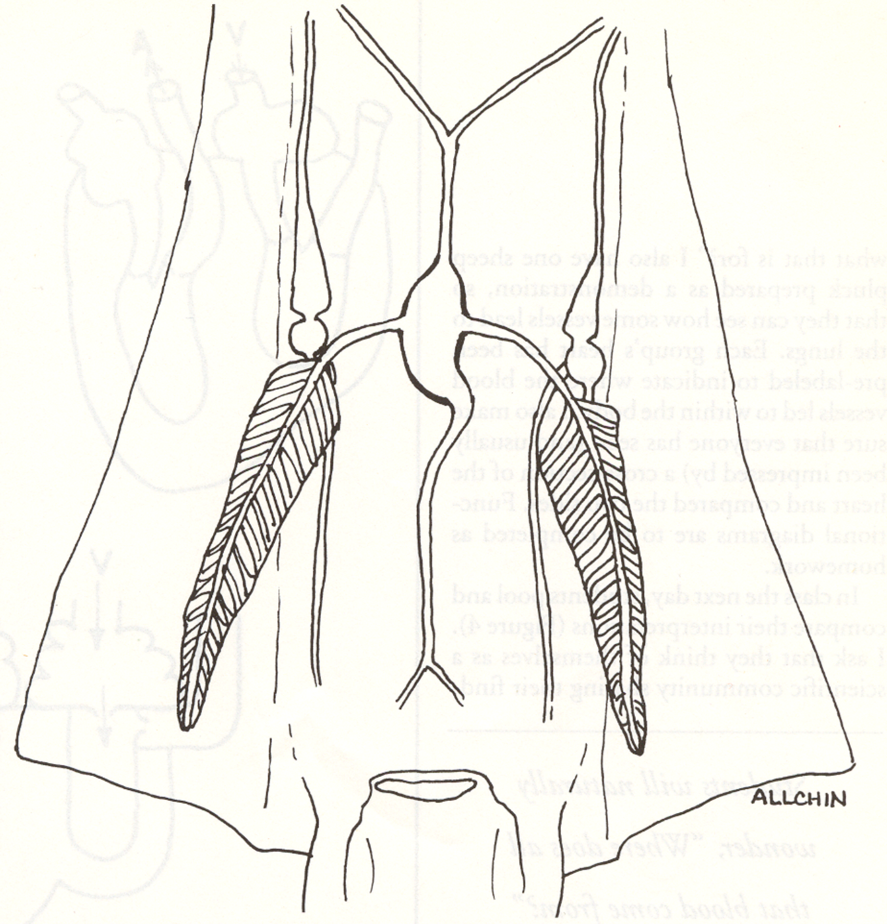


FIGURE 6. Historical highlights.

1605 The gunpowder plot of Guy Fawkes to blow up King James I is foiled when 36 barrels of gunpowder are found under Parliament.

1607 Capt. John Smith lands in Virgina and establishes the first permanent settlement in the New World—named Jamestown.

1609 Henry Hudson sails into a harbor on the east coast of America.

1611 A new authorized edition of the Bible—the King James version—appears.

1616 William Shakespeare, the Great Bard, and Miguel de Cervantes, Spanish author of the epic *Don Quixote,* both die.

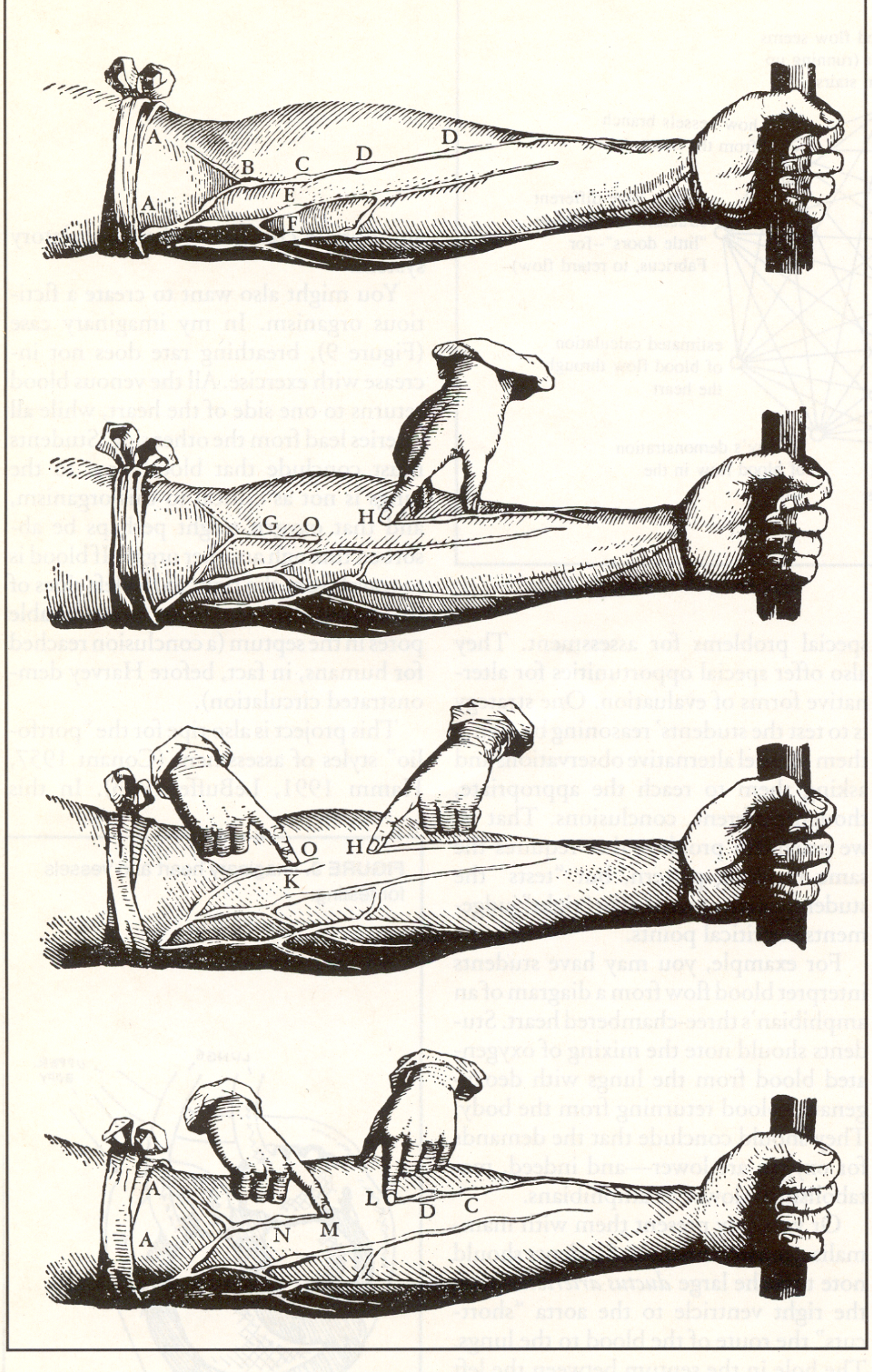
Galileo is warned by the Catholic Church that he should not defend the Copernican view that the Earth revolves around the Sun.

William Harvey lectures on the circulation of the blood at the Royal College of Physicians in London.

Because we must account for all the vessels, we must ask wether blood flows, counter-intuitively, *into* the heart. The initial interpretation of the squid is perhaps key, here, to unraveling the whole explanation (and it is the strongest clue I ever give to the students). Oddly, the very observation not used by Harvey may be the one most helpful in promoting a successful "historical" simulation.

We may also begin to reason productively from Harvey's demonstration of blood flow in the arm: blood must flow towards the heart as well as away from it. Does this relate to the squid's hearts, to the thickness of heart walls, or, perhaps, to the "little doors" in the veins? Students may find that, like Harvey, they must challenge the pre-existing notion of Fabricus that the valves control blood as it flows *away* from the body. Also, are the flaps in the heart related to the flaps in the veins? What does the volume of blood flow mean? If we decide that blood goes out one set of vessels and back along

FIGURE 7. Harvey's demonstration (from De motu cordis, 1628).



others, how does it get from one to the other? Again, students may find, just as Harvey did, that they have to be confident enough with their other conclusions to predict the existence of yet unobservable vessels.

There are, of course, many paths to assembling the facts into a coherent theory. Most of the concepts can emerge from the students on their own, given time and encouragement. At most, the instructor should assume the role of a fellow investigator and offer only sample questions, not actual hints. Clearly, for the project to be successful as a genuine discovery, the teacher must participate as little as possible in the actual problem-solving: you must see yourself as a facilitator or "conceptual midwife." Discussion is complete when all the observations (Figure 8) are explained.

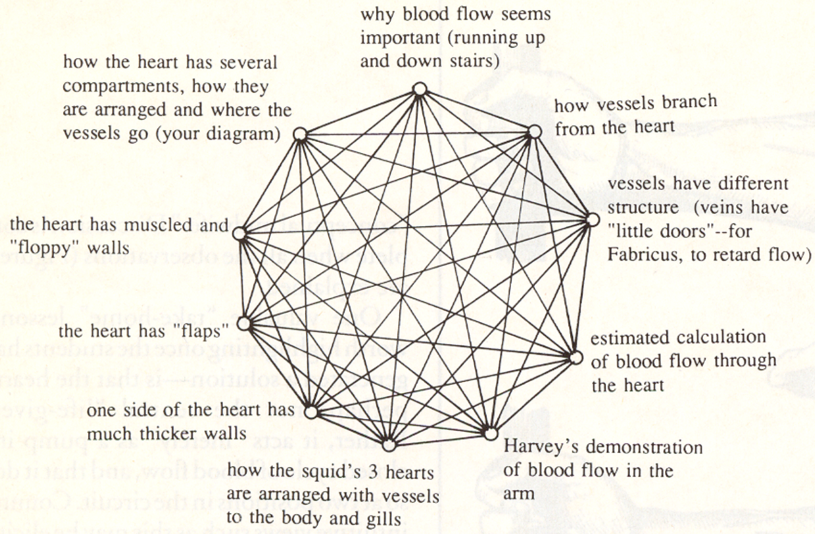
One valuable "take-home" lesson—worth highlighting once the students have generated a solution—is that the heart is perhaps not the central "life-giver." Rather, it acts "merely" as a pump in a closed cycle of blood flow, and that it does so at two positions in the circuit. Counter-intuitive views such as this may be elicited by reversing student-teacher roles and by asking, for instance, "But doesn't the heart give a sort of energy to the blood?" We may articulate, once again, what the blood carries, from where and to where.

Finally, I reveal Harvey's own conclusion and validate the class' work by noting the respect now accorded to Harvey. Yet we should also appreciate how we often "corrupt" a historically sensitive view of Harvey. Harvey saw the blood as endowed with a vital spirit, akin to the forces of the stars that influenced human destinies. For him, the heart was as central as the life-giving Sun, and the circulation of blood was a microcosm of the forces that flowed through the Universe:

The heart is the beginning of life; the Sun of the microcosm, even as the Sun in his turn might well be designated the heart of the world; for it is the heart by whose virtue and pulse the blood is moved, perfected, made apt to nourish, and is preserved from corruption and coagulation; it is the household divinity which, discharging its function, nourishes, cherishes, quickens the whole body, and is indeed the foundation of life, the source of all action.

Harvey saw the heart as serving an Aristotelean final cause. For him, the heart regenerated the heat of the blood—what gave the blood motion and nourishment; the thick walls of the heart protected this heat. Harvey's views may be set in the context of what the students themselves know about eating and

FIGURE 8. Sample "think homework."



breathing, and where the intestines, lungs, liver, kidneys, and "target" cells are located. Again, the squid's separate hearts, showing no single central organ, may provoke discussion. Transport, it may be concluded, is distinct from direct nourishment.

CREATIVE ALTERNATIVES

Many variations on this exercise are possible. Richard Eakins, for example, has cast the episode in first-hand testimony by performing the role of Harvey himself. His provocative and entertaining, *Great Scientists Speak Again,* provides a possible script. Also, vivisection was certainly important among Harvey's observations and for his arguments; it has been omitted here, obviously, because of the ethical distinction between contexts of education and research. A film re-enacting Harvey's demonstrations, however, is available from the Royal College of Physicians (be advised, though, that this film is graphic). Some may want to follow the contemporary context more closely. We might emphasize, for example, the mechanical analogies important for Harvey and others: bones and muscles as levers, the lungs as bellows, and the heart, of course, as a pump (Frank 1980).

EVALUATION

Historical simulations, and the reasoning skills we want students to develop, pose special problems for assessment. They also offer special opportunities for alternative forms of evaluation. One strategy is to test the students' reasoning by giving them parallel alternative observations and asking them to reach the appropriate, though different, conclusions. That is, we provide a problem that requires the same thinking pattern, but "tests" the student's ability to make the "right" judgements at critical points.

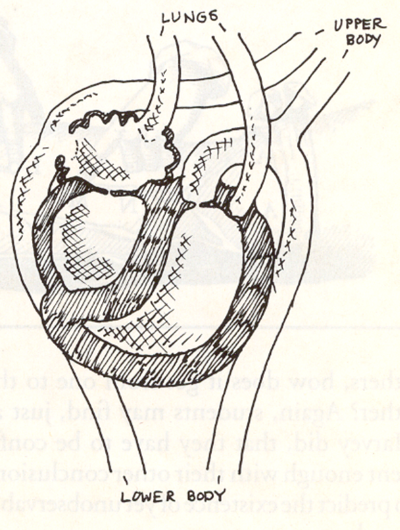
For example, you may have students interpret blood flow from a diagram of an amphibian's three-chambered heart. Students should note the mixing of oxygenated blood from the lungs with deoxygenated blood returning from the body. They should conclude that the demands for oxygen are lower—and indeed, metabolism is slower in amphibians.

Or you may present them with mammalian fetal circulation. Students should note that the large *ductus arteriosus* from the right ventricle to the aorta "shortcuts" the route of the blood to the lungs. The hole in the septum between the left and right atria likewise bypasses the pulmonary system by routing the blood more directly to the left ventricle. "Why is fetal circulation different?," you may ask. Clearly, the blood is oxygenated via the umbilical cord. The fetus "breathes" through the placenta, not the lungs. (This can open a disucssion of the dangers of "blue babies" who are born without the appropriate changes in their circulatory system.

You might also want to create a fictitious organism. In my imaginary case (Figure 9), breathing rate does not increase with exercise. All the venous blood returns to one side of the heart, while all arteries lead from the other side. Students must conclude that blood flow to the lungs is not as critical to this organism, and that oxygen might perhaps be absorbed through another organ. If blood is to travel from the right to the left sides of the heart, there must be unobservable pores in the septum (a conclusion reached for humans, in fact, before Harvey demonstrated circulation).

This project is also ripe for the "portfolio" styles of assessment (Conant 1957, Hamm 1991, LeBuffe 1993). In this

FIGURE 9. Imaginary heart and vessels for testing.



framework, a final evaluation might be based on the student compiling a formal presentation of the argument. This might include their original lab diagram, and possibly a version revised through experience; a diagramatic interpretation of the squid blood flow; and an essay, akin to a real scientific paper, in which the function of the heart is discussed or "argued," and evidence for circulation is presented.

The portfolio might include suggestions or plans for further investigation. Diagrams can be encouraged; working models might be accepted. You should probably ask that the "think-homework" include a reflective self-analysis, with suggestions made by the student for approaching similar problems in the future.

Likewise, you could have each student include a self-evaluation of his/her contribution to the collaborative problem-solving effort. Because the students have all participated in the same activity, there is also the opportunity for peer evaluation of portfolios (easing your burden some).

HISTORICAL SIMULATIONS IN GENERAL

This activity on circulation exemplifies more broadly how we can apply history to teaching both concepts and processes of science more effectively (Roach 1993, Erhardt 1991, Schamp 1991). That is, the history of science is a "how-story" of science that models how concepts or experiments can develop. Through historical simulation, we can also revive the context of inquiry and thus tap the students' curiosity as a natural motivation (rather than through some artificial gimmick).

We may find, in particular, how to address students' unschooled intuitions and frequent misconceptions, or how to teach about conceptual change. But we may also creatively adapt or "corrupt" the history to suit our aims. We can only imagine, in this case, whether Harvey would have appreciated how squids can further the understanding of circulation that he pioneered.

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OTHER RESOURCES

The Search for Solutions. Film/video series, 18 min. each, available free of charge. Write *The Search for Solutions,* c/o Philips Petroleum Co, C-25 Phillips Bldg., Bartlesville, OK 74004.

Creativity: The Human Resource. Filmstrip available from: Chevron Film Library, One Rockefeller Ctr., Suite 1710, New York, NY 10020.

William Harvey and the Circulation of Blood. 4th Ed. 15-mm, color, 30 min. Available from the Royal College of Physicians Film Library, c/o CFM Distributers Ltd., Pottery Lane House, Holland Park, London, England W11 4LZ.