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Feature
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How Animals Work

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INTRODUCTION

Molecular biology and advanced techniques informed by chemistry and physics have changed biological research and teaching. Today's students take for granted that as they study the life sciences, they will hear a lot about genes and molecules. Sir William Harvey would be profoundly disorientated and then gratified by a visit to the Harvey Society's website (www.harveysociety.org). The man who accurately described the functional anatomy of the circulatory system would appreciate the extent to which his evidence-based approach to animal physiology has won the day. Indeed, understanding life processes at a molecular level is immensely satisfying. Three cheers for reductionism (Figure 1).

It can be difficult, however, to fully appreciate the beauty of molecular details if the larger functions they serve are poorly understood. After all, it is the anatomical genius of the circulatory system that ensures that every cell of the body benefits from the marvel of hemoglobin. The steadily growing body of biological information makes it more challenging to preserve places in the curriculum to provide organismal and physiological context for students, and to cultivate deep thinking about how complex biological systems function through emergent properties of molecular mechanics. We are all interested in how our bodies work and are obsessed, if not enthralled, by our innards, or as one website (http://iheartguts.com/) would put it, "we heart guts."

My main goal for this review is to uncover websites that can be used to infuse the biology curriculum with systems and organismal context. Because a human anatomy and physiology (A&P) sequence is still part of most life science curricula, websites that support the teaching of A&P vastly outnumber websites concerned with general physiological principles or comparative physiology and anatomy. I highlight websites that emphasize fundamental principles and a comparative approach, but I also point to several excellent sites devoted to human A&P (Figure 2).

To honor Harvey, let's begin by looking at a website that does an outstanding job of showing how our hearts work. The Knowledge Weavers website (http://library.med.utah.edu/kw/) from the University of Utah medical library offers many excellent resources. Their Flash-animated heart (http://library.med.utah.edu/kw/resources.html#animations) is one of the best of many available on the Web. The action of the heart is linked to dynamic graphs of blood pressure/volume, electrocardiogram, and heart sounds. The progress of the heart cycle is tracked by systole and diastole, in turn subdivided into relevant phases, and controls are available to run the animation fast, slow, or in step-through mode. The Flash console conveniently locates links to tutorials. The tutorials, by dissecting the animation step by step, should help students consolidate their learning based on the animation. It would be an interesting assessment to have students make their own tutorials and then see how they measure up to those made by the website authors. In addition to the cardiology information, the site also has an interesting concept for presenting a functional neural pathway. The Osteointeractive section (http://library.med.utah.edu/kw/

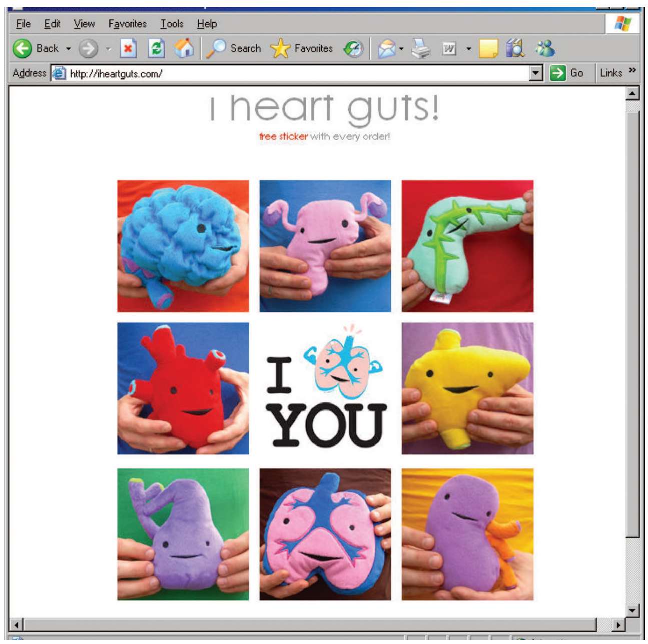

Figure 1. The i heart guts website sells plush toys based on most of your favorite internal organs.

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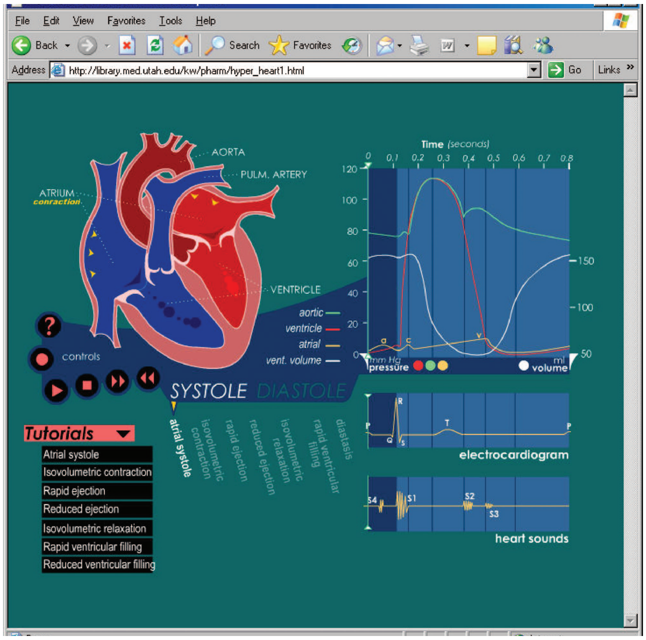

Figure 2. The University of Utah Medical Library has a number of outstanding educational resources and tutorials on its Knowledge Weavers website, including an excellent animation of the circulation through the heart.

osteo/index2.html) is noteworthy in presenting topics such as forensic anthropology and paleopathology, including the use of bones for human rights work. They've also developed tools to help faculty make multimedia and Web-based quizzes.

WEBSITES WITH PRINCIPLES

Sometimes it seems like the nonmajors have all the fun. Some of the best sites for explaining fundamental principles of how animals work (e.g., countercurrent exchange and homeostasis) are aimed at beginning biology students. Oklahoma State University hosts a handsome website (http://zoology.okstate.edu/zoo_lrc/biol1114/index.html) associated with their Introductory Biology course for nonmajors. The website by Donald French includes study guides, content flowcharts, and a set of animations associated with the course. Unfortunately, some of the materials are password protected, but the section enigmatically entitled Scenario Software is open and worth viewing. The scenario called Fire and Ice (http://zoology.okstate.edu/zoo_lrc/biol1114/study_guides/scenarios/2-Fire_and_Ice/fireiceSCNR.html) offers good animations and an interesting approach to illuminate several important aspects of animal physiology, including thermoregulation, countercurrent exchange, and osmoregulation. As a result of French's engaging introduction, students who thirst for more rigor on the principles of countercurrent exchange, for example, might want to visit Johan Koeslag's Web pages (http://academic.sun.ac.za/medphys/counter.htm). Although the site offers only static HTML pages, the illustrations are clear. After an introduction to the principles of countercurrent exchange, Koeslag presents examples of countercurrent exchange in marine mammal limbs, gas exchange in alveoli, and salt exchange in the loop of Henle (Figure 3).

In vivid contrast to Koeslag's more traditional approach, the University of Wisconsin's Connecting Concepts website (http://ats.doit.wisc.edu/biology/lessons.htm) uses humor and everyday life to engage students in understanding how their bodies work. The homeostasis activity follows Ben, a student who is having a bad day. Topic 1 details Ben's day, as he has trouble with lagging energy and keeping warm. Topic 2 uses graphics to relate Ben's "day" to the activity of his nervous and endocrine system. Topic 3 addresses whether Ben might have diabetes. The Instructor Manual is a useful 11-page pdf document that summarizes the various Web-based activities. The copyright on the material is 2003, and I found the navigation clunky by current standards. I like the content ideas and the approach, but I wish the website worked more smoothly (Figure 4).

The Connecticut College human physiology animations page (www.conncoll.edu/academics/departments/biology/humanphysanims/muscle.html) was developed by Ben Hayes, Bess Bayne, and Stephen Loomis. The interactive animations are simple and effective, but I wish more topics were covered. One effective example is Feedback Loops under Endocrine System Animations. It introduces the topic of homeostasis by starting off with a thermometer and building to a thermostat. Students can see how improper wiring results in a feed forward circuit that spins out of control, instead of a feedback circuit that maintains homeostasis. A similar treatment of homeostasis can be found at other websites. The University of Pennsylvania Health System has an animations library (http://pennhealth.com/health_info/animationplayer/) composed of dozens of animations produced by the A.D.A.M. media company (www.adam.com). The homeostasis animated tutorial begins with the thermostat analogy, and then it focuses on the endocrine system and the regulation of sugar balance by insulin. Al-

Figure 3. The University of Wisconsin's Connecting Concepts website uses humor and daily life to engage students in learning about homeostasis.

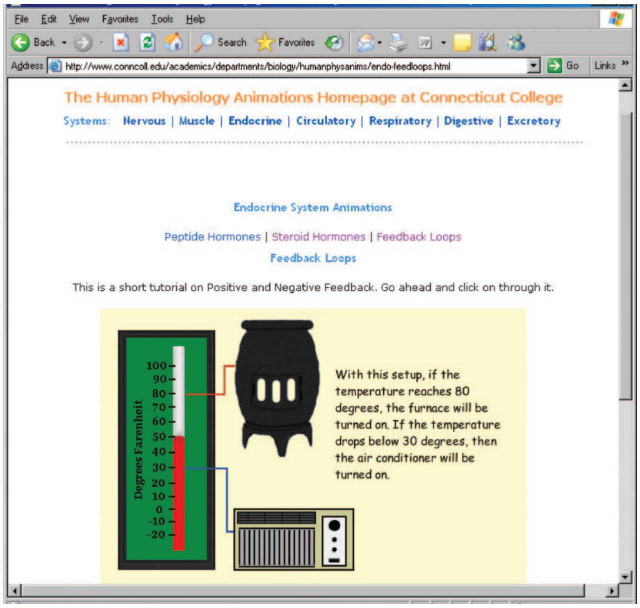

Figure 4. The Connecticut College human physiology animation page includes an interactive animation demonstrating how homeostatic systems, like thermometers, work.

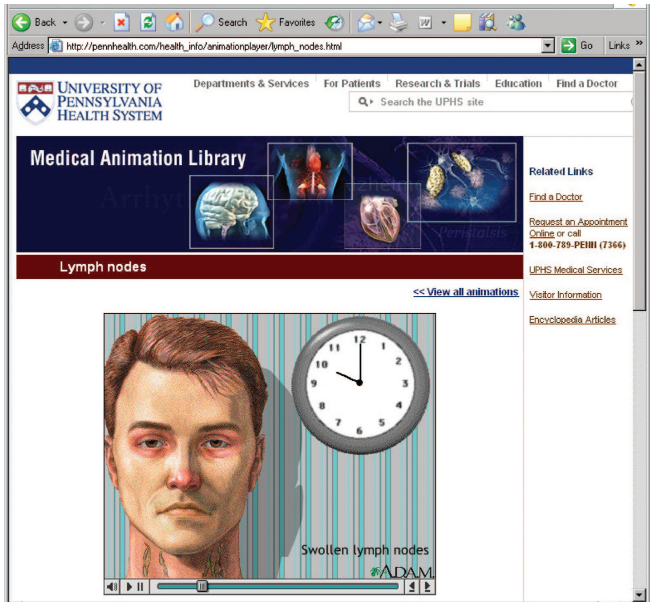

Figure 5. The University of Pennsylvania Health System has a library with dozens of animations done by A.D.A.M. Software, including one on the functional anatomy of the lymphatic system.

though A.D.A.M. established a reputation for providing anatomy content, their animations always emphasize functional anatomy. You can get a feel for their approach by viewing Breathing, which shows the cycle of airflow and all the relevant structures at tissue and organ levels, or the Lymph nodes, in which the anatomy is presented but the emphasis is on functional understanding and disease processes. It is fantastic to have all of these animations freely available in one place (Figure 5).

FUNCTIONAL ANATOMY

In keeping with the theme of functional anatomy, there are several websites that do a good job of integrating A&P for a deeper understanding, and they make anatomical material easier for many students to learn and remember.

North Harris College Biology Department has assembled one of the most comprehensive sites for A&P animations (http://science.nhmccd.edu/biol/index.html). The animations are organized by the standard topics covered in the typical first (http://science.nhmccd.edu/biol/ap1int.htm) and second (http://science.nhmccd.edu/biol/ap2int.htm) semester of anatomy and physiology. For A&P Part I, the topics include Skin, Skeleton, and Joints; Muscular System; Nervous System; and Endocrine System. These animations are collected from sites around the world, and although there is nothing fancy about the navigation or presentation, having them in one place is very convenient. The vertebrate motor unit animation, for example, under Muscular System, is one of the little gems that can be hard to find if you are out trolling on your own. On the A&P Part II website, the topics include Cardiovascular, Immune, Digestive, and Reproductive systems. It's obvious that an effort has been made to assemble the best animations to be found, but because these animations are produced by diverse authors, the style and quality vary, from the simple graphics of the motor unit animation, to the elegant interactive graphics of The Juxtaglomerular Apparatus found under the Urinary heading. Speaking of urinary, I've mentioned the Sumanis website (www.sumanasinc.com/webcontent/animations/biology.html) previously (*CBE—Life Sciences Education* 6, 266–270, 2007, and *CBE-LSE* 5, 94–98, 2006) and they have an excellent animation on the mammalian kidney. Sumanis continues to add high-quality material concerning blood flow, ovarian cycles, and reflex arcs, to name a few (Figure 6).

Good material can crop up in surprising places. The Houston Independent School District has a remarkable collection of animations on the human body. The website (www.hisdbenefits.org/hisd/living/animations/) seems to be aimed at employee health education in connection with employment benefits. Although biology students are not the intended audience, and the topics are all health related, the animations are very good for providing a physiological and anatomical context for health-related problems. For example, if you click on hyperlipidemia, you are introduced to the structure of a cholesterol molecule, and then given an overview of blood and circulation as context for understanding the causes and health consequences of hyperlipidemia. Sir William Harvey would smile. The animation window is too small but the animations and narration are good. You also have the option of viewing still graphics ("slides") and text of the narration.

Figure 6. The Houston Independent School District has a vast collection of health-oriented animations that emphasize functional anatomy and disease processes.

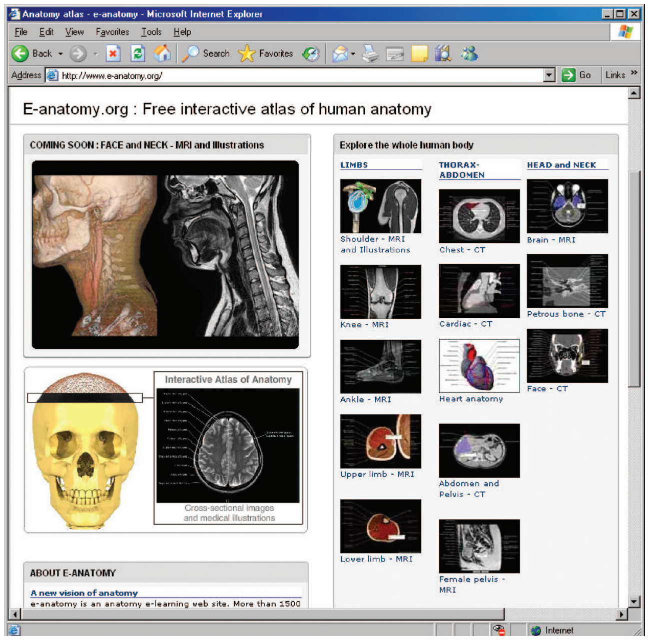

Figure 7. Campus Medica's interactive atlas of human anatomy has an elegant interface that allows the user to move rapidly through serial CT and MR optical sections of human organs.

HUMAN ANATOMY WEBSITES

I prefer teaching and learning anatomy in a functional context, but the typical A&P curriculum still tends to emphasize memorization. Clearly, comprehensive Web-based anatomical references are convenient and useful regardless of how you teach your students (Figure 7).

The Maricopa Community College in Arizona has assembled a website (www.gwc.maricopa.edu/home_pages/crimando/Tutorial_Big.htm) with some good reference tutorials. The Skeletal and Muscle tutorials use mouse-over and other labeling techniques for identifying bones and muscles. Other systems are under construction, such as respiratory, digestive, and urinary.

The University of Wisconsin at Lacrosse hosts a website (http://bioweb.uwlax.edu/APlab/Index.htm) with some of the clearest anatomical images on the Web, including large clear labels. You can use the table of contents or just browse pages like an online book.

The Interactive Atlas of Anatomy by Campus Medica (www.e-anatomy.org) is one of the more elegant anatomy websites. The images were compiled from >1500 computed tomography and magnetic resonance imaging optical sections of the human body. The interface allows you to "cine through" the image series as if you were scrolling through optical sections in real time.

Notre Dame's LUMEN Master Muscle List (www.meddean.luc.edu/lumen/MedEd/GrossAnatomy/dissector/muscles/muscles.html) lists all the muscles in the human body in alphabetical order. Each muscle is presented with a highly schematic graphic on a virtual index card that shows the muscle location, origin, insertion, action, and associated nerve.

The University of Washington Digital Anatomist Project (www9.biostr.washington.edu/da.html) features high-quality anatomical models, with an impressive interface for finding and viewing various gross anatomical sections of the human body. A movie feature shows the orientation and location of any given section (Figure 8).

For those who prefer being as close to the real thing as possible, Gary Nieder at Wright State University has built a Quicktime Virtual Reality (QTVR) feature (www.anatomy.wright.edu/QTVR/library/library.html) that supports rotating an image for 360° viewing. If you click on a collection (e.g., Organs then Cardiovascular), several shelves of specimens will be presented to you in QTVR. The images are large (1000 × 1400 pixels; >13 MB), so manipulating in QTVR is much like seeing the actual specimen.

TEST YOUR KNOWLEDGE

If it is necessary to memorize material, interactive websites can be an aid for many people. In addition to providing the material in a format that may be more engaging or convenient than a book, the Web also can provide interactive quizzes and games.

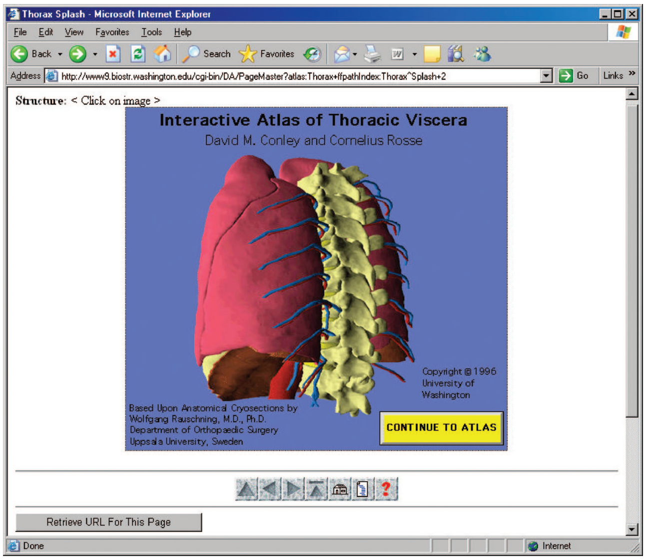

Figure 8. The University of Washington Digital Anatomist Project features high-quality anatomical models and animations to provide context and orientation.

The publisher Wiley has assembled (www.wiley.com/college/apcentral/anatomydrill/) a collection of interactive quizzes for Anatomy Drill and Practice. Level 1 quizzes provide labels that you click and drag to the appropriate anatomical graphic, whereas level 2 quizzes require you to type in the correct answer. There are >100 quizzes covering all the major systems and levels of tissue organization. I tended to do well on level 1 quizzes, but I had a much harder time if I started out with a level 2 quiz. The regime that seemed to help me the most was to struggle with level 2, and then work on level 1, and return to level 2. This routine could be accomplished in a pretty short time compared with reading a textbook. To pass level 2, you not only have to recognize *tensor fasciae latae*, you also have to spell it correctly. Another publisher, Pearson, has a very similar collection of quizzes (http://media.pearsoncmg.com/bc/bc_marieb_ehap_8/activities/index.html) but without the level 2 text input option. McGraw Hill also has a human anatomy quiz site (www.mhhe.com/biosci/ap/vdghumananatomy/student/olc2/ap_animation-quizzes.html). Most quizzes start off by asking you to view an animation first, and the animations, like Striated Muscle Contraction, are quite good. And finally, the University of Minnesota's WebAnatomy pages (http://msjensen.cehd.umn.edu/webanatomy/) push the gaming aspect of testing your knowledge by adding timed tests and multi-player contests.

QUALITY COMPARISONS

We lose a lot of life's wonder, and the essential evolutionary perspective, if we give students the false impression that studying one ape, one rodent, one fish, one insect, one nematode, and a handful of microbes can capture all of biology. Much of what we understand in just the narrow arena of mammalian physiology is due to comparisons of marine and terrestrial mammals, or marsupials and placental mammals. When nature produces adaptations for extreme conditions, scientists are provided with a great learning opportunity. Although I did not find large, comprehensive sites on comparative anatomy and physiology, there are many smaller websites that provide pieces of the puzzle, and I'd like to close with some examples of websites that could be used to build illuminating comparisons (Figure 9).

A lot can be learned about what makes us uniquely human by comparing our skeletons to our primate cousins while asking questions about posture, locomotion, load bearing, and other lifestyle features. The University of Texas eskeletons website (www.eskeletons.org/) is a good resource for comparing primate skeletons—the graphics are excellent. The interface and search functions take a little time to learn, but they are worth the effort. As we extend the context of what it means to be human, it's natural to move from primates to other mammals. Undergraduates at Duke University have put together a handsome comparative mammalian anatomy site (www.baa.duke.edu/companat/BAA_289L_2004/index.htm). Do most mammals have the same number of muscles, and can the same naming conventions be used? What are the exceptions to the general rules and patterns? For most structures, the website features dissections of an interesting cast of diverse mammals: beaver, cat, opossum, pig, rabbit, and rat.

Humans have a peculiar brand of locomotion called bipedalism. Our love of sports, and the fact that athletics is a trillion dollar industry, means that a fair amount of information on human movement can be found on the Web. The University of San Francisco offers a website (www.usfca.edu/ess/tis/) devoted to providing resources to teachers of kinesiology and biomechanics. For example, under Labora-

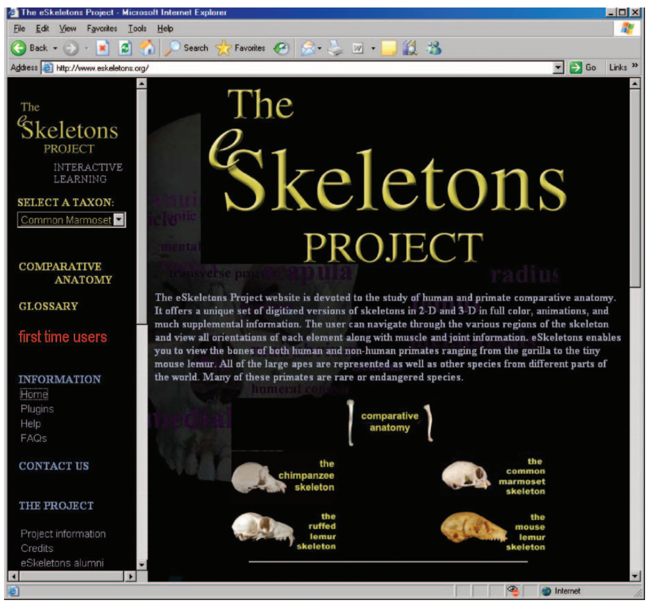

Figure 9. The eSkeletons project of the University of Texas is designed to facilitate comparison among various primate species.

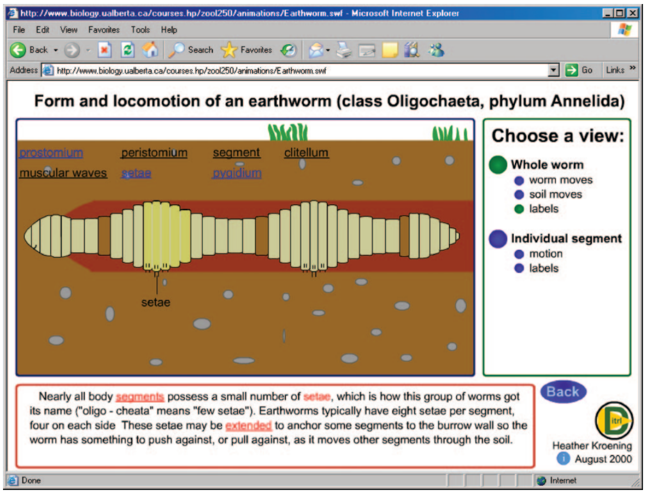

Figure 10. The University of Alberta hosts an exemplary animation on the functional anatomy of the earthworm as it relates to their peculiar form of locomotion.

tory Exercises, you can find a Running Kinematics lab that has video clips of athletes running at various speeds, which can be analyzed using standard equations that relate cycle length and time to speed. Northwestern University's kinesiology website (www.smpp.northwestern.edu/~jim/kinesiology/animations/INDEX.HTM) lets you view an animation showing the pattern of leg muscle activation during walking. How does the human pattern compare with other animals, such as a horse? A motion capture company called Kinetic Impulse has a beautiful website (www.horselocomotion.com/horse_motion_capture_data_faq.html) that showcases many of the classic kinematic photos of animal locomotion. Scrolling down, you can find Muybridge's classic horse series and a movie of a galloping horse. How does this tetrapod gate differ from our own? Are we able to gallop? Why? How have our bodies adapted to our bipedalism, and what could you deduce by comparing the anatomy of a horse and a person? How did we come to be bipedal in the first place? You might visit the NOVA Web pages (www.pbs.org/wgbh/nova/allfours/bipedalism.html) to ponder this question further, take a vote, and then see what experts have to say (Figure 10).

Comparing human locomotion to that of an earthworm might be stretching the comparative method beyond usefulness. In any case, I do recommend that you visit Heather Kroening's site (www.biology.ualberta.ca/courses.hp/zool250/animations/Earthworm.swf) to see a stellar animation of earthworm locomotion. Kroening's approach is simple and informative. I would like to see a similar module for other forms of locomotion, such as animal swimming or flight, not to mention locomotion of microbes (www.abac.edu/kmccrae/BIOL2050/Ch1–13/Animations/Animations.html).

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