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Creation, Evolution, and the Human Genome

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Students are generally introduced to topics of diversity and heredity in 7th and 8th grade science classes. These topics are explored further in a variety of Biology courses during the first or second year of high school. This unit is aimed primarily at students in the upper grades of high school for whom an interdisciplinary setting might provide rich interplay between scientific evidence and broad reaching ideas and questions about evolution.

In my school, a magnet public high school of about 240 students, I have undertaken the development of just such an interdisciplinary science and humanities course with one of my colleagues from our English Department. During one quarter of the year (nine weeks) students can enroll in an intensive seminar of this nature which meets for three hours daily. Although this may seem to most teachers to be an enormous amount of time to prepare for, it offers exceptional opportunities for extended study, research, writing, and discussion. In this unit I present an overview of the science curriculum for this seminar; my colleague has prepared separately a plan for the humanities curriculum. Since we teach together for the entire three hours daily we blend ideas and draw upon each other as resources throughout the course.

For the purposes of organization, I have divided the unit into three themes:

I. The Origins of Life: Creation vs. Science?

This first theme sets the stage for inquiry and seeks to engage students at a variety of levels, providing “hooks and handles” for the humanities component of the interdisciplinary seminar through readings from several creation myths and posing some “unanswered questions in science.”

II. Theories of Evolution

> A brief background in development of theories of evolution—from the early Greek philosopher-scientists to the modern day molecular biologists. After Darwin two lines of study developed in pursuit of knowledge about human evolution—fossil hunters and geneticists.

III. The Chemical Basis of Life

Evolution from the perspective of late 20th century theorists—the molecular geneticists. The human genome, the pinnacle of chemical organization of human life, provides a glimpse, or snapshot, of the leading edge of present day evolution among humans and the arena for mutation and change in the future.

I. The Origins of Life: Creation vs. Science?

Objectives: Students should be able to

1. explain the purpose of creation myths.
2. compare and contrast two different myths of creation and identify common themes and differences.
3. explain the difference between "creationist" and scientific views of life.
4. compare and contrast "hypothesis" and "theory" and give an example of each.
5. distinguish the characteristics of science from pseudoscience.
6. explain how a scientist works to resolve an "unanswered" question of science.

Strategies:

1. Copies of several creation myths will be provided for study. Small groups of students will read, discuss, and present each myth to the class.
2. Reading of examples and discussion of relationships among biology, technology, and ethics.
3. Lecture: Introduction to Charles Darwin's life and work as one example of a scientist using observation—hypothesis—experiment—prediction—theory.
4. Development of concept map to distinguish between science and pseudoscience.
5. Written summary of class discussion of the Huck Finn and Jim debate over the origin of stars.
6. Group study and discussion of unanswered or "open" science questions—written summary by students for sharing with the class, based on reading of articles:1
    a. Did the Universe Have a Beginning?
    b. Did Life on Earth Arise by Chance?
    c. Where Did the First Animals Come From?
    d. Do We Share Common Ancestry With Apes?

Discussion: We had the sky, up there, all speckled with stars, and we used to lay on our backs and look up at them, and discuss about whether they was made, or only just happened—Jim he allowed they was made, or only just happened; I judged it would have took too long to make so many. Jim said the moon could a laid them; well, that looked kind of reasonable, so I didn't say nothing against it, because I've seen a frog lay most as many, so of course it could be done. [2]

In Mark Twain's classic American novel, *Huckleberry Finn* , quoted above, Huck and Jim ponder the world and how it came to be. Without knowing much science or philosophy or religion, they wrestle with the profound question of whether some ultimate purpose lies behind the world. Is all existence the result of a creator—God, or of self-directed forces of happenstance (or, perhaps, to some combination of "first cause" and random after effect)?

At the heart of wisdom is the search for an answer to that question. If stars "only just happened, "then nature can be seen as merely due to random, accidental events and processes. This answer might imply that human beings are only physical objects without value or intrinsic worth. Likewise, if stars were "made" then perhaps all nature was meant to be. All living things might be viewed as purposeful, bearing the signs of a creator's intentions. Life takes on a sacred dimension. Humans, especially, become obligated to treat each other and their whole earthly environment with dignity and respect. A sense of connectedness and interdependence among living organisms is a common thread which runs throughout creation myths from widely different cultures. Perhaps a resurgence of this awareness accounts in part for the recent large scale outpouring of concern for the future of the earth.

But there is a danger in over-romanticizing this "creationist" interpretation of life. When Huck and Jim decide that the moon gave birth to the stars, their answer, however satisfying at the moment, makes no sense from a scientific standpoint. It is contradicted by too much evidence.

The welfare of any modern nation depends on its science and technology. U.S. industry, national defense, even health, rely on progress in fields such as geology, physics, and genetics. Science implies scientists, who must be accurately taught. In schools and colleges, there can be no contamination of the teaching of science by irrelevant philosophies or prejudices, no matter how time honored these may be. [3]

Philip Dunne, in the above statement published recently, emphasizes our current predicament as science educators: Science teachers today are often wary of an ongoing controversy—the American public seems divided over what students should be taught about origins, particularly human origins. Yet when science is properly taught, questions of origins become opportunities for classroom dialogue. Students who learn to distinguish between scientific discoveries and the assumptions buried within them gain a better appreciation of what science is. Similarly, an understanding that a scientific *theory* is not a "guess," but a well-tested hypothesis which not only explains evidence but predicts future data, can eliminate some of the popular confusion which posits belief in the Bible, Koran, or other religious canons as equal to "belief" in science.

For some of the deepest questions about life's meaning and purpose, religious faith is part of the investigative process. The methods of science seek to investigate the *how and when* , but cannot step outside nature to probe why things exist or whether a greater intelligence lies behind our own existence. [4] "The mystery of creation, as every real scientist is quick to admit, is not one that science is capable of solving." [5] For many students, however, the two sets of questions ("how" versus "why") appear confused and entangled.

Scientific knowledge keeps expanding and thus students must always be taught some things that were unknown when their parents went to school. But good science teaching means more than conveying information about what scientists have learned. A more vital task is teaching the particular way that scientists look at the world. The fact that this way may not be fully appreciated by even technologically sophisticated students makes the prospect quite challenging. Valid scientific conclusions are based on valid evidence. Students need to learn how to evaluate evidence as scientists are trained to do—essentially taking all relevant facts into consideration while searching for still more evidence. How the world works is what scientists are continually investigating, and research has led to tremendous improvements in food, medicine, health care, computers, etc. However, in gaining knowledge, scientists have also challenged the way people think and this sometimes causes problems. To provide both rationale and guidelines for constructive classroom dialogue, students will need to clarify terms and practice the skill of identifying similarities and differences between the concepts of "science" and "pseudoscience." Drawing a concept map as a lecture/note taking exercise may help achieve these goals.

Creation or Evolution—A False Dichotomy

Creation myths and stories—the mineral-rich bedrock of religious thought—offer explanations for the origins of human life as experienced by the peoples from whom the myths developed. Whether serendipitous act, Supreme Intelligence, godly conflicts, or other "first cause" is identified in the myths, they have in common the attempt to explain human interactions and foibles, interdependence and relationships among living things, relation of life to earth, or purposes of life. The heart of religion is searching for meaning and in this quest curiosity about what came before as well as what might follow is often addressed.

In biology, evolution is often presented historically as an idea or concept which gradually replaced the early 19th-century concept of a "static" creation in which not much had changed since "the beginning." Geological evidence accumulated during the 18th and 19th centuries to such an extent that scientists became convinced Earth had a very long history of changes. Examination of the evidence for physical changes of the earth revealed forms of life that were no longer existent. None of the present life forms had been on the earth throughout its entire history and human beings seemed to be newcomers to a comparatively very old planet.

It is commonly believed that science and biblical (revealed) religion have always been at war with each other. Such belief is not supported by historical study. Western science and religion went hand-in-hand in the reading of earth's history for centuries. The static view of the world had been the commonly accepted interpretation of both the physical data and the biblical creation story. It is reasonable to venture that science did not advance until scientists overcame their religious assumptions and viewed evidence from a new perspective.

Perhaps, surprisingly, biblical imagery—an orderly creation by a dependable, consistent God—was one factor that freed the reins of science and gave a strong push toward development of understanding of the natural world. In a world which religion had proclaimed both "good" and the product of Supreme Intelligence, observation, measurement, description, and prediction were both possible and necessary. Galileo, a devout Christian, is reputed to have said that the Bible "taught how to go to heaven" but science explained "how the heavens go." (Of course, it must be noted that Galileo spent the last years of his life under virtual house arrest because he refused the Roman Catholic Pope's demand that he repudiate his observations of the orbits of planets about the sun, in contradiction to official church doctrine that the earth is the center of the universe. It was not until the early 1980s, 300 years after Galileo's death, that the Roman Church officially acknowledged modern science by quietly publishing an edict pardoning Galileo!)

Even in Darwin's time, many religious believers accepted evidence for great changes over long periods of geological time without losing faith that such changes were ultimately the work of a Supreme Being. They were comfortable with separating questions of when new forms of life appeared from questions of how this happened. "the modern picture of how life changed over time was developed by geologists who believed in divine creation. The geologic column and the basic facts of fossil succession were established in science (and accepted by most theologians) by about 1840, some twenty years before Darwin proposed a mechanism to explain how such changes had taken place." [6] Human interest in evolution had always been more complex than simply the opposition of scientific versus religious viewpoints. As legal historian Edward J. Larson had pointed out, science teachers deal not so much with science itself but with "public science"—a compromise between scientific thought and public policy which has a complicated history. [7]

After the famous Scopes trial during 1925 in Tennessee, evolution nearly disappeared from American high school textbooks, reappearing only after the Soviet Union launched Sputnik in 1957. [8] Sensing an urgent need for improved mathematics and science education, the federal government funded a variety of curriculum development projects including the Biological Sciences Curriculum Study (BSCS). Several high school biology texts produced by BSCS were integrated around evolutionary concepts. BSCS has kept up with the explosive growth of information and ideas in biology since the first publications and its sixth edition of *Biological Science — A Molecular Approach* published in 1990 offers an exceptionally thorough treatment of current biological concepts for advanced high school students. Although evolution remains a key organizing concept, the latest text has been broadened to include among its unifying themes diversity, genetic continuity, environment, science and society, history of biological concepts, and science as inquiry. This text is most highly recommended for students studying topics in genetics and the unfolding of evolutionary thinking.

Even with the virtually universal acceptance by scientists of evolutionary theory and the publication of highly acclaimed, authoritative, and clearly explained texts such as the BSCS editions, there is still some lingering controversy over human origins and evolutionary development in the realm of "public science," which is, after all, where we all teach. Within the last two decades dedicated, well-organized groups have promoted the teaching of "creationism" or "creation-science"—perhaps the best example of "pseudoscience" since the Midas and the alchemists. Numerous court battles have been waged in attempts to promote "theories of creation" as deserving of equal time with theories of evolution in science classrooms. In every case, culminating in 1990 with the U.S. Supreme Court decision *Edwards v. Aguillard* , the creationists have been defeated, primarily because creation concepts do not fit the fundamental definition of science which holds that theory derives from data collected through observation and experimentation. [9] Every step of the scientific process must be open to scrutiny, review and reproducibility of results. As the old joke goes, "God never secured tenure among the scientific community because He or She performed an experiment which no one has been able to repeat, peers could not be found to review the work, and He or She only published one book!"

As teachers of diverse middle and high school students, we must recognize that we are treading on fascinating but tender ground when we raise questions about human origins. In the world of public science, integrity of our scientific training demands that we teach that scientists defend evolution because they regard it as a key biological concept. Meanwhile, many American citizens cherish creation as a basic religious doctrine or concept. Direct conflict between these concepts or world views can erupt at any time in discussion or can underlie a student's responses in writing. Integrity to our overlap pedagogical training demands that we be sensitive to our students' wrestling with a controversy—at whatever level it grasps them. I urge teachers to "seize the opportunity," however it presents itself, to move students along in their understanding of the concepts and in their sensitivity to how they and their classmates feel about the nuances and implications of various theories and ideas. Standard techniques for guiding classroom discussion will be helpful: a brief review of seven suggestions focused on evolution has been prepared by the American Scientific Affiliation and may prove a valuable teaching resource for this unit.

Conclusion:

Writers of mythologies, free to roam the breadth of human imagination, are "limited" by the extent of their linguistic expression. Modern scientists—even armed with vast new technologies—are limited by the constraints of a discipline which requires inquiry to meet rational, quantitative standard. Yet math and science have in common a searching, investigative outlook toward life. As paleontologist Stephen Jay Gould recently stated:

> . . . there are about half a dozen scientific subjects that are immensely intriguing to people because they deal with fundamental issues that disturb us and cause us to wonder. . .[scientific study of] evolution is one of those subjects. It attempts, insofar as *science* can, to answer the questions of
>
> what our life means,
> why we are here,
> where we come from,
> who we are related to,
> what has happened through time, and
> what has been the history of this planet.
>
> These are the questions that all thinking people have to ponder. [10]

II. Theories of Evolution

Objectives: Students should be able

1. To outline the history of thinking about evolution.
2. To give examples of the evidence used to develop and defend theories of evolution.
3. To identify several key thinkers in the history of evolution and their contributions to the debate.

4. To explain the differences between Darwin’s and Lamarck’s theories.
5. To explain the meaning of “natural selection” and give an example of its operation as a mechanism of evolution.
6. To apply Darwin’s theory to the history of human evolution, with particular attention to differences between Neanderthals and Cro-Magnons.
7. To draw a timeline of the hominid family tree.
8. To explain the scope of modern molecular biology.
9. To compare and contrast the two strands of scientific study of human origins—morphology and molecular biology.

Strategies:

1. Watch Smithsonian video, “Tales of the Human Dawn,” and construct a timeline of the hominids as a small group exercise.
2. Research and construct a timeline of the early ideas of evolution.
3. Read selections from *BSCS* , Chapter 1, and draw a concept map to compare and contrast Darwin’s and Lamarck’s theories.
4. Develop a “Who’s Who” of Evolution chart—individual student research and brief reports to the class.
5. Read the “Lucy” article by Johanson on the discovery of the most complete *Australopithecine* fossil.
6. Oral reports on key scientists and discoveries in development of molecular biology.
7. Watch the movie “Race for the Double Helix” and discuss the significance of discovery of DNA molecular structure for evolution.

Discussion: Evidence for evolution has become so pervasive that to inveigh against it is similar to King Canute requesting the retreat of the tide. [11]

In 1977, William V. Mayer, director of the Biological Sciences Curriculum Study, could make the above claim with no dispute from the scientific community and strong reaction only from religious special interest groups within the larger population. This was not always the case, however.

The publication in 1859 of Charles Darwin's *Origin of Species* touched off such broad debate and publicity about evolution that it still echoes in the public press and popular culture today—overshadowing, unfortunately, the great scientific strides in understanding and collection of evidence in the 100 years since Darwin. As one entertaining illustration of this point a class session might be spent analyzing, discussing, and sketching cartoons from a variety of popular artists (Gary Larson, Jim Davis, Burke Breathed) who make their bread and butter from humorous depictions of "Darwinian" evolutionary ideas. "Darwin" and "evolution" have become so inextricably linked in common lore that it may come as a great surprise to students to learn that evolution was a concept established long, long before Darwin and that "the current status of evolution bears about the same relationship to Darwin [and his finches] as today's quantum physics holds to Newton [and his apple]." [12]

Attempts to explain the origin of life and the diversity of living things are as old as human history itself. In ancient myths can be found the strands of searching for answers to evolutionary questions. But not only myths reflect the roots of this quest. Students will possibly be interested in tracing the line of scientific theorizing about life as sketched in the time line below. [13]

The earliest written records of the Greeks reveal formulation of hypotheses about evolution:

636-546 B.C.

Thales , an early philosopher, theorized in writings about the origin of life.

611-547 B.C.

Anaximander conceived the idea of gradual evolution from a formless chaotic condition to ordered, organic life. He even held view of adaption and transformation of aquatic species to land.

495-435 B.C.

Empedocles outlined a concept of gradual evolution—plant species preceding animals and better adapted forms replacing others. (William Mayer makes a case for Empedocles as a more appropriate choice than Darwin as the founder of the evolutionary idea.)

The emergence of the Christian Church with its doctrinal control promoted the dogma of "special creation"—essentially a literal interpretation of the biblical Genesis story. This did not, however, completely stifle attempts by some of the early and later church theologians to reconcile the idea of evolution with scripture:

331-396 A.D.

Gregory of Nyssa , although believing that God created the fundamental properties and laws of nature, believed that present existence developed gradually out of chaotic material, a viewpoint similar to that of

Anaximander.

335-430 A.D.

Augustine , among his many writings, developed an interpretation of the biblical account of creation as allegoric.

1225-1274 A.D.

Thomas Aquinas , an Augustinian scholar, supported his views and suggested that the earth had received the power to produce organisms, further questioning the Genesis creation ordering and time frame.

By the late 16th century, scientific and philosophical thinking in the west was no longer under total control of religious authorities. Alongside a rising movement for reform within the Christian Church came an upsurge of early enlightenment philosophy aggressively seeking to stretch the boundaries of human understanding:

1561-1626 A.D.

Francis Bacon , the English philosopher, revived the idea of evolution during this time of challenging the dominant religious world view. With spreading enthusiasm, *Descartes* (1596-1650), *Leibniz* (1646-1716), *Kant* (1724-1804), and others pushed open the doors of inquiry which led the great naturalists of the 18th and early 19th centuries to explain how evolution had occurred.

1707-1778

Carl Linneaus , while not specifically examining evolution, developed the system of classification of plant and animal kingdoms which is the basis of modern understanding of relationships and diversity.

1707-1788

Leclerc de Buffon contributed the idea that environments can directly modify plant and animal structure, and that these changes may be conserved through heredity.

1731-1802

Erasmus Darwin , the grandfather of Charles, raised questions about organisms' internal source of adaptations, rather than the impact of the environment. He recognized the importance of a struggle for existence, but did not carry this idea far enough to propose "survival of the fittest" (leaving that as a legacy to his grandson!). Erasmus did, however, challenge the concept of a "young earth" and argued, along with the Scottish geologist James Hutton (1726-1797) that millions of years would be required for rock formation and evolutionary processes.

1744-1829

Jean Baptiste Lamarck extended Buffon's ideas to propose a theory that a change in environment produces a need for change in animals and that acquired characteristics in one generation will be passed on to the next. (This well-developed theory should be carefully compared with the Darwin/Wallace theory of evolution by natural selection.)

1797-1875

Charles Lyell , another British geologist, developed the theory of "uniformitarianism" regarding natural phenomena. "The present," he said, "is key to the past"—natural forces that created the world are still at work and change is a slow, unending process. Although speaking directly in reference to development of physical features of the earth, Lyell had a great influence on Charles Darwin's thoughts about plant and animal evolution.

1809-1882

Charles Darwin did not originate the concept of evolution, as should now be obvious. However, along with Alfred Russel Wallace (1823-1913), he developed the theory of evolution "by natural selection." Darwin's theory was based almost entirely on inferences rather than verification of hypotheses by experiment. "It stands as a unique triumph of this scientific method and has become essential for comprehension of biology as the atomic theory is for chemistry and physics." [14]

Two decades before publishing The Origin of Species, *Charles Darwin* wrote in his notebook: "Man in his arrogance thinks himself a great work, worthy the interposition of a deity. More humble and I believe true to consider him created from animals." [15] If any one aspect of Darwin's outlook touched off the Victorian maelstrom of reaction to his theory, repercussions of which are still felt today, it was this suggestion of the relationship of humans to the rest of nature.

Two main strands of scientific inquiry have developed over the century since Darwin's publication: paleontology and genetics.

The first, which students are most likely to be familiar with, is the search for fossil evidence linking present day human morphology to earlier, less evolved hominids. The Smithsonian video, "Tales of the Human Dawn," and recent articles from weekly news magazines [16] will provide ample material for student discussion of human ancestors and the current thinking regarding the human family tree.

The discovery of "Lucy," the most complete Australopithecine fossil, as described by Johanson [17] , makes the field work of paleoanthropologists appear as lively as any successful treasure hunt. For students who wish to pursue further this area of science, the work of Louis and Mary Leaky or their son, Richard Leaky, will provide interesting topics to research. Historically, worth studying is Thomas Henry Huxley (1825-1895), the British zoologist who defended Darwin's theory of natural selection, who asserted early on that he believed humans evolved from apes. Of interest in American science is George Gaylord Simpson (1902-1984), a paleontologist who classified the evolution of mammals and showed in his work that the fossil record is compatible with Darwin's theory of natural selection.

As mentioned previously, the idea of human evolution is deeply rooted in popular culture and is reflected in stories, movies, and humor of all types. It will be particularly helpful to students who may range from ambivalence to firm beliefs to help them understand that thorough scientific inquiry is ongoing regarding human ancestry, and that theories will serve only as long as they can stand the test of further observations and research.

The second stream of scientific inquiry regarding evolution has given rise to fields of study and disciplines unknown to Darwin. Darwin would have been quite at home with the paleontologists, biogeographers, anthropologists, and comparative anatomists of the first stream of study. He would be astounded, perhaps, to see the evidence accumulated in the 20th century by cytologists, molecular geneticists, biochemists, and molecular biologists. A brief history of the development of this scientific strand will set a context for student study of modern genetics:

1882

Walter Flemming published his results on the study of cell mitosis, detailing the role of chromosomes in cell division.

1884

Gregor Mendel , within five years of the publication of Darwin's world-shaking treatise, The Origin of Species, developed a theory of inheritance based on carefully controlled experiments with pea plants. He discovered that parents can pass on characteristics to their offspring through the action of discrete units of inheritance (named "genes" by the Dutch geneticist Wilhelm Johannsen in 1909), each controlling a specific trait.

1900

Hugo De Vreis , a Dutch botanist, concluded that evolution was the result of the sudden appearance of new varieties (which he called mutants) and not the natural selection of shifting variations proposed by Darwin.

1903

Walter Sutton observed that in cell division producing sperm or egg cells, each gamete receives only one chromosome of each original pair. He recognized that chromosomes must be the carriers of the Mendelian heredity units and hypothesized that parental sperm and egg each contribute one chromosome to each new individual.

1910

Thomas Hunt Morgan developed studies on the chromosomes of the fruit fly (Drosophila melanogaster), and by 1920 he and other researchers firmly established the chromosome theory of heredity. Further work showed that chromosomes are regular linear arrangements of genes.

1931

Barbara McClintock demonstrated that gene order in chromosomes can change by rearrangements and that specific traits in strains of corn are tied to their genetic distribution.

The natural selection ideas of Darwin and the De Vries mutation theory could now be seen as complimentary—"natural selection was found to be picking and choosing among variations in the genotype to produce effects for the whole organism." [18] Genetics and evolutionary theory merged in the 1930s, contributing to the formation of new fields of study (e.g, population biology, population genetics, *molecular genetics* , biochemical genetics, *molecular biology*). The final important key in this development was the merging of genetics and biochemistry with focus on the molecular basis of life: molecular genetics explains the mechanisms behind Mendelian genetics while molecular biology concentrates on the structure of cell components to uncover the "code" that determines the characteristics of an organism.

1944

Oswald Avery , Colin MacLeod, and MacLyn McCarty discovered DNA (deoxyribonucleic acid) as the material of the gene. DNA is a long chain molecule made up of four different kind of molecular groups (nucleotides).

The leaps in scientific understanding that occurred between 1859, when Darwin published *Origin of Species* , and 1952, when a group of research scientists knew that DNA was the very controlling molecule of life, are of tremendous significance. (For students seeking to understand the role and importance of scientific inquiry in explaining life processes, a brief study of any of the key investigators named might prove informative.)

Immediately after the biological importance of DNA was recognized, its physical structure was discovered:

1953

James Watson and *Francis Cric* k determined the structure of DNA as a "double helix"—a sort of twisted ladder shape—with spines made of sugar and phosphate and rungs made of pairs of the four bases adenine, guanine, thymine, and cytosine.

1958

Meselson and Stahl , investigating how the DNA molecule manages to reproduce itself so exactly as cells in a developing organism divide and multiply, confirmed that the double spiral "unzips" along its length and nucleotides then link up with each half of the chain to form two duplicates of the original model.

The modern age of molecular biology, which has been chiefly concerned with how genes control cell activity and how proteins carry out tasks such as DNA and RNA formation, began with Watson and Crick's determination of the helical structure of DNA. [19] The technical and conceptual developments over the past three decades deserve far more treatment than can be included in this unit. This unit does, however, seek to establish the background and context from which students may launch into future study of genetics and biology (hopefully at undergraduate and graduate levels.)

It is not unreasonable, once a common vocabulary and language of discourse has been established, to introduce very recent discoveries, techniques, and possibilities. Today the study of DNA has been revolutionized by procedures collectively referred to as "gene cloning" and "recombinant DNA technology." DNA from any organism can be cut into reproducible pieces, joined to plasmid DNA, and introduced into bacterial hosts for culturing and reproduction on a large scale.

The breakthroughs and benefits for medical science are constantly in the news and will be familiar to many students and certainly deserve study and discussion to relate to basic knowledge and familiar models. Researchers at Yale University and in several local companies are available to meet with students and share with them their excitement about developing potential cures for everything from the common cold to deadly cancers and AIDS.

Have molecular biologists displaced Darwinian ideas about evolution? Hardly. It might be more accurate to say that the focus has shifted with advances in concepts and technology, but the fundamental theory remains much the same. Whereas Darwin studied animal morphologies (e.g, the famous finches' beaks), today's theorists study minute structures within cells thanks to electron microscopy, gene splicing, and electrophoresis techniques, among others.

The discovery of DNA provides at least a new round of tentative answers to questions concerning heredity, origins of diversity in life, and animal and plant development. In the argument of one recent text, the discovery that DNA is the universal genetic material of cells suggests that

1. Early evolution must have depended on development of a cell carrying sufficient *instructions in its* DNA to grow;
2. The random variation and selection proposed by Darwin and Wallace that led to changes in species must have resulted from *random changes in the DNA* ;
3. Faithful *reproduction of DNA* from generation to generation causes "like to beget like;"
4. The programmed instructions in the genetic endowment in *DNA underlie the development* of every new plant or animal. [20]

Conclusion:

An interesting way to draw together various ideas in the history of evolution would be an examination of the debate currently stirring in popular science circles concerning the origin of modern humans. Billed by *Discover* magazine as "the big battle between bones and genes," [21] this is a case study of the quest for an answer to the same question by two very different branches of science—paleoanthropology and molecular biology—each operating with its own assumptions, techniques, and rules. DNA exists in human cells chiefly in the nucleus. Outside the cell, however, nuclei are rod-like mitochondria within which there is also a form of DNA. This "mitochondrial DNA" is unique in that it apparently is inherited only from the mother. (Nuclear DNA is combined genetic material from both mother and father.) The only differences between mitochondrial DNA of a child and that of its mother, grandmother, or great-grandmother are the result of random mutations, according to evolutionary theory. Vincent Sarich and Allan Wilson, two biochemists at Berkeley, have hypothesized that mutations occur across millennia at a steady rate, establishing a kind of "molecular evolutionary clock." [22] By studying genetic differences and calculating backwards in time with their clock, Sarich and Wilson establish dates of divergence among species and within the hominid family, the emergence of modern humans.

On the other hand, paleoanthropologists use field evidence—bones, tool fragments, fossils—and geologic or radiocarbon dating techniques (assuming another form of steady rate clock) to establish emergence dates. Significant differences in the timing of human evolution result from the two techniques and hence the debate. Once students have gained a solid understanding of cell structure and DNA they may be prepared to delve further into this debate.

Of most fascination is the possibility that future studies of the mitochondrial DNA may lead scientists back along the trail of human evolution toward an ancestral female "Eve," breathing new life into the mythologies considered in Section 1 of this unit.

III. Chemical Structure of Life—The Human Genome

Objectives: Students should be able

1. To explain the relationships among atoms, molecules, elements, and compounds.
2. To explain and give examples of inorganic and organic compounds.
3. To name the six most common elements in human bodies
4. To relate the characteristics and functions of the four classes of macromolecules and give examples of each.
5. To explain how enzymes catalyze chemical reactions.
6. To recognize the importance of nucleic acids to inheritance.
7. To describe the structure of a nucleotide.
8. To describe the structure and replication of DNA.
9. To explain what a gene is.
10. To define the human genome and explain its significance.
11. To explain the significance of mutation in DNA.
12. To describe the human genome mapping project.

Strategies:

1. Reading, lecture, note-taking.
2. Cooperative learning in small groups to develop diagrams and concept maps.
3. Molecular model building.
4. Construction of nucleotide and DNA models.
5. Microscope slides and projector slides of human chromosomes.
6. Guest lecturers from Bios Corporation and Yale School of Medicine, Human Genetics Department on study of genomic DNA and inherited disorders.

Discussion: Molecular biology is not trivial aspect of biological systems. It is at the heart of the matter. Almost all aspects of life are engineered at the molecular level and without understanding molecules we can only have a sketchy understanding of life itself.
— Francis Crick [23]

In teaching a molecular view of life to students in high school it becomes quickly apparent that, however uncertain they feel about basic tenets of evolution theory, they seem universally to accept an atomic theory of matter from previous science study. I find it useful, therefore, to provide a quick review of atoms—elements, molecules—compounds, following a basic text in biology or chemistry. It helps to have a periodic chart and to point out to students that of the some 112 known elements, 92 are naturally occurring (and quite likely have been present since the beginning of earth). Of these 92, only about 18 are usually found in living things. And among these 18, the six most essential to human life are oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorous.

Elemental atoms bond together in various combinations to form molecular compounds. *Inorganic* compounds such as water (H2O) and carbon dioxide (CO2) exist regardless of living organisms. *Organic* compounds are produced by living organisms and/or by synthetic means, but in all cases this class of compounds contains carbon as an essential bonding element, usually combined with hydrogen and oxygen. Generally, organic compounds are more structurally complex than the inorganics.

Carbon can combine in long chains that form the backbone of large, complex macromolecules in which the carbon atom backbone is called the carbon skeleton—appearing in straight chain or ringed form to which other atoms attach themselves.

Four groups of macromolecules are present in living systems:

1. **carbohydrates** (e.g., sugars, starch, cellulose)
2. **lipids** (e.g., fats and oils)
3. **proteins** (several thousand types exist made by the linking of amino acids with peptide bonds; the type, number, and sequence of amino acids distinguishes one protein from another. Specialized proteins, called “enzymes,” serve as catalysts to lower the energy required for reactions to proceed within the living cell.)

4. **nucleic acids** (passed from one generation to another, it is nucleic acid which stores information determining the genetic characteristics of cells and organisms; nucleic acids are the macromolecules that dictate the amino acid sequence of proteins which then control all basic life processes.)

Nucleic acids are made of units, called *nucleotides* , joined into long chains. Each nucleotide contains three parts:

1. sugar (either deoxyribose or ribose)
2. a phosphate group (PO3)

3. a nitrogen base—either a single or double carbon ring with nitrogen and hydrogen. See diagram 3.1 for the four bases found in DNA (Adenine = A. Thymine = T. Cytosine = C. Guanine = G).

(figure available in print form)

Figure 3.1 The four nitrogen bases in DNA

Ribonucleic acids (RNA) contain ribose sugar in their nucleotides while deoxyribose acids (DNA) have deoxyribose sugar. DNA molecules have two long chains of nucleotides intertwined to form a double helix. (See figure 3.2.) The backbones of the spiral are made of the sugar-phosphates while the rungs are chemically-bonded nitrogen bases. Note that the bases always have very specific pairing: *A to T* and *G to C* . (This is the structure which Watson and Crick deduced in 1953.)

(figure available in print form)

Figure 3.2 Double helix structure of DNA

(based upon diagrams in *Mapping our Genes — The Genome Projects* . OTA-BA-373, U.S. Congress, Office of Technology Assessment)

The structure of DNA quickly led to an understanding of how this crucial molecule replicates itself in the course of cell division. During cell division, the DNA double helix unwinds (or "unzips"), the weak bonds between base pairs break, and the DNA strands separate. Free nucleotides are then matched up with their complementary bases on each of the separated chains, and two new complementary, identical, double helix chains are made. Figure 3.3 illustrates the beginning of this process. Students will benefit greatly from a laboratory exercise in small groups constructing and replicating their own models of DNA.

(An extension of the exercise will allow students to construct RNA using their DNA molecules as a guide and then to show how the RNA moves out of the cell nucleus to provide the code for construction of proteins at the ribosomes.)

(figure available in print form)

Figure 3.3 Replication of DNA by "unzipping" of the molecule and attachment of free nucleotides to each strand.

(based upon diagrams in *Mapping our Genes — The Genome Projects* . OTA-BA-373, U.S. Congress, Office of Technology Assessment)

The Genome

The genome is the total genetic material (DNA) present in a single cell nucleus. Each of an adult human's 10 trillion cells, except for reproductive cells (gametes) and red blood cells, contains essentially the same DNA—3 billion basepairs (bp) divided into 23 pairs of physically distinct units called "chromosomes."

Each chromosome has a single compressed DNA molecule whose bases average 150 million that would be 2 inches long if released from the cells and stretched out. DNA molecules are the largest known molecules. [24]

If all of the DNA in one person's cells were stretched out, it would reach to the moon and back! [25]

Chromosomes are visible under the light microscope and a set of slides is available in the Teachers' Institute Library for class use. (Magnification of 400x works well.) Stains reveal a pattern of bands on the chromosomes that reflect variations in the amount of A,T,C,G bases in regions. Differences in size and banding allow each of the 23 chromosomes to be identified and in some cases abnormalities can be spotted by eye that indicate differences in the genomes. Most DNA details, however, can only be detected by molecular techniques. Abnormal DNA may be responsible for inherited diseases or cancer.

Genes are segments of DNA (sequences of bases) which directly convey genetic information as well as the information used by cells to regulate the kind and amount of protein they make. The human genome (3 billion bp) has 50,000 to 100,000 genes. Typically, a gene may contain up to 30,00 bp, but only 10 percent of these pairs are known to contain useful information (exons), while the rest are considered to be stuffer or "junk" (introns). There are about 3,000 to 4,000 genes per chromosome. [26]

A government sponsored, 15-year human genome project is underway to decipher the complete code of the 50,000 to 100,000 genes—essentially to determine the exact order of the base pair sequences. To accomplish this, the genome must be broken down into genes or other fragments small enough to be clones and then identified. Next, the fragments will be arranged or "mapped" in their respective locations on the chromosomes. Finally, automated techniques will be employed to determine the base sequence of the ordered fragments. The ultimate map will be the base pair sequence for the entire human genome—a "snapshot," if you will, of the genetic code for the "standard" human being at that moment in time.

As researching this area continues, specific human genes are being identified and mapped or located on specific chromosomes. In 1958 only a handful of gene loci were known; by 1987 nearly 4300 genes were located. [27] As any reader of newspapers can tell, new genes are being located nearly daily.

An illustrated lecture is outlined in the lesson plans to assist students in grasping the scale of the genome project. If the number of base pairs of DNA in human cells is considered roughly comparable to the number of people on earth, then mapping the entire sequence of base pairs in one cell is a task comparable to identifying every single person on earth by name and location!

When the human genome map is complete, will it match any individual exactly? No, there is simply far too much variation among specific individuals to expect 3 billion base pairs to line up exactly with the standard sequence. Since all healthy humans have essentially the same genes (only identical twins have exactly the same genotype), the map will provide an exceptionally accurate diagnostic tool.

How Does the Human Genome Compare With Other Genomes?

Before much was known about the DNA sequences of genomes, it was assumed that the amount of DNA would increase in proportion to the biological complexity of the organism. Since chromosomes can vary in size, the total amount of DNA is a better indication of genome size than the number of chromosomes. Higher plants and animals do have much more DNA than lower organisms. There are, however, interesting exceptions, such as the salamander which has DNA content more than 30 times greater than that of humans, even though it is a smaller, less complex organism. Even the cells of some species of plants have more DNA than human cells as shown in the table below:

(Haploid) Amounts of DNA in Various Organisms28

Organism	Millions of Base Pairs
Bacterium	4.7
Yeast	15
Nematode	80
Fruit Fly	155
Chicken	1,000
Human	2,800
Mouse	3,000
Corn	15,000
Salamander	90,000
Lily	90,000

Mapping of human and other species' genomes will enable comparative studies to be done to determine genomic sequences or genes which are conserved among widely varied species. Even without full knowledge of the genomes, it is possible to do comparative evolutionary studies by matching a known sequence probe to the DNA of various species using well established gel electrophoresis and hybridization techniques. The results will show degrees of relatedness or divergence among species with dramatic implications for the construction of evolutionary trees. [29]

Within any single species, hereditary variation is the result of changes occurring by mutation—changes in the sequence or number of nucleotides—which occurs during DNA replication. Mutations formed in sex cells are inherited by offspring, whereas those that occur in other cells remain only in the affected organism. Some diseases, such as human cancers, can be caused by factors in both of these categories. Mutations can also be the result of artificial causes, such as exposure to radiation or certain chemicals. A change in even just a single base pair may modify or shut down a protein, if one is encoded in the altered region of the chromosome. More extreme mutations, involving changes in structure of a chromosome or number of chromosomes can also occur.

In diploid cells, each DNA molecule has a tendency to undergo some modification or rearrangement with each cell division. [30] In meiosis, two rounds of cell duplication occur, resulting in four daughter cells, each with a haploid set of chromosomes. Before the first division, each member of a chromosome pair is replicated, forming two sets of chromosome pairs. At this stage, the cell has two identical copies of maternal origin chromosomes, and two identical copies of paternal origin. An event called "crossing over" or "recombination" can occur in which one maternal and one paternal chromosome exchange corresponding sections of DNA. In this way, two of the four resulting sex cells have chromosomes with new combinations of genes and thus new combinations of traits are created.

Conclusion

What actually happened [in evolution] makes sense. It's just that what actually happened is one of a billion possible alternatives. . .if you could play life's tape again from any early point, you'd never get it to run exactly the same way again. [31]

Since Linneaus, biologists have classified animals according to similarities and differences in form and structure. These physical features were used to establish lineages—"family trees" or evolutionary relationships among species. Today, new methods of genetic analysis are challenging morphology as the key to determining family trees. The potential power of genetic techniques for evolutionary studies lies in the growing acceptance that the driving force behind structural changes in organisms is the constant minuscule molecular mutation of DNA.

The human genome as we are coming to know it is but one brief chemical moment in evolutionary time. However, it is our moment; and the scientific and technological advancements promised by a full understanding of the genome's complexity will fuel a vigorous research effort for at least the next decade.

Lesson Plan 1: "Tales of the Human Dawn"

Materials:

Video, "Tales of Human Dawn," Smithsonian World, 1989. 50 minutes.
Copies of Pima Indian creation myth (provided with rental of video from Smithsonian World)
Copies of glossary (provided with video rental from Smithsonian World)
Overhead transparency: "Timeline of Hominid Evolution" (also available from Smithsonian World)

Educational Themes:

1. Humankind's various interpretations of origins.
2. Origin myths and their implications concerning human self-perception and behavior.
3. The evidence in fossil record of early humans and theories to explain the findings.
4. Uniquely human characteristics.

Previewing Activities:

1. Brainstorm characteristics that define what it means to be a fully modern human. List responses, have students divide them into two categories: physical and cultural.
2. Discuss: What do the characteristics say about Homo sapiens in comparison with other animal species? (Prior lecture on genus, species classification will be needed—students need to know we are genus Homo, species sapiens, subspecies sapiens to separate us from an earlier, now extinct group, Homo sapiens neanderthalensis.)
3. Give students copies of the glossary; preview terms which will be used in the video.
4. Review definitions of various fields of science—paleontology, paleoanthropology, archeology.

Discussion:

What kinds of specific information does each science contribute to our understanding of early humans? Why is it important for us to know about early history of Earth and our own species?

Postviewing activities for discussion and writing:

1. Are humans truly different from the other animals? What arguments are used to make the case for human beings' special place in nature?
2. Why have people in every culture created origin myths? What does this tradition of creation stories say about how humans view themselves?
3. How do science and mythology differ in their approach to the unknown? How does each explain natural phenomena? Do science and mythology ever overlap? Explain.
4. Divide into groups. Have each group read a different creation myth and then present it to the class as a story or skit with interpretation of its meaning.
5. Bipedal walking, versatile hands with opposable thumbs, binocular vision, and large brain distinguish humans from other animals. To demonstrate how changing just two of these attributes changes the way we live, have each student tape his thumbs to the palms of his hands and put a patch over one of his eyes. Let them spend a few minutes in regular classroom activities. What activities are particularly difficult? What behavior adaptations are necessary?
6. Construct a wall chart of the hominid timeline. (Research may be needed—see Lambert's *Field Guide to Early Man* .)

Lesson Plan 2: “The Children of Eve”

Materials:

Video: “The Children of Eve.” NOVA, 1990, 55 minutes.
Glossary (adapt from video, as appropriate)
Visual aids—model or overhead transparency of a cell, DNA

Educational viewing goals:

1. Review Sarich and Wilson’s experiment that caused them to hypothesize that hominid and ape lines split only 4-6 million years ago.
2. Recount arguments for and against existence of a steady molecular clock.
3. List two theories that explain why bipedalism evolved.
4. Discuss why some evolutionists believe that the Neanderthals could not have evolved into the Cro-Magnons.

Discussion: Almost 20 years ago, Vince Sarich and Allan Wilson challenged the traditionally accepted date of 15-29 million years ago for the divergence of human and ape lines. Have the class discuss the experiments that support Sarich and Wilson’s more recent divergence date of 4-6 million years ago. What are the arguments for and against their steady clock? What is the Sarich and Wilson theory of evolution? What is their critics’ theory?

Suggested activity: Invite a molecular biologist to visit your class to discuss what he or she does on a daily basis. Ask the speaker to bring some common tools used in his or her field of work. Where does the scientist expect his or her area of research to lead?

Follow-up: Divide students into groups and assign each one of the recent news magazine articles listed below. The group’s task is to read and discuss the article among themselves and construct a concept map to present to the class summarizing key themes in their article.

Recommended reading

1. Shreeve, J. “Argument Over a Woman.” In *Discover* , v.11, no.8 (Aug. 1990): 52-59.
2. Gould, S.J. “Where We First Stood.” In *Discover* , v.7, no.5 (May 1986): 52.

3. Pfeiffer, J. “Cro-Magnon Hunters Were Really Us, Working out Strategies for Survival.” In *Smithsonian* (Oct. 1986): 75.
4. “The Search for Adam and Eve.” In *Newsweek* , (Jan. 11, 1988): 46-52.

Lesson Plan 3. Modeling Structures of DNA and RNA

Materials:

One roll of adding machine tape, felt pens
stapler, scissors, masking tape for each group
8 different colors of construction paper to cut to about 3” x 5” pieces (for consistency in the room, assign colors to A, C, T, G, U, phosphate, ribose sugar, and deoxyribose sugar)

Objectives:

1. Students will practice cooperative learning in small task groups.
2. Students will assemble materials to form the nucleotides needed to form DNA and RNA.
3. Students will be able to construct and sketch a model of the DNA molecule, labeling all component molecules.
4. Students will be able to demonstrate and explain replication using their models.
5. Given a DNA molecule model, students will be able to demonstrate transcription (conversion of DNA code into RNA code)
6. Students will be able to identify quickly DNA and RNA models and compare and contrast them.

Procedures:

1. Divide the class into task teams of 3-5.
2. Each group should devise paper shapes and label them to represent models for the bases Adenine, Thymine, Cytosine, Guanine, and Uracil so appropriate pairs fit together like jigsaw pieces. (Teacher should provide a sample)
3. Decide paper shapes and colors to represent phosphate, ribose, and deoxyribose, and label "PO3," "r," or "d" appropriately.
4. Groups should construct 5 paper nucleotide models (using bases A, C, T, G, U)
5. Construct a paper model of a DNA sequence encompassing at least 15 base pairs—the adding machine tape will serve as spines of the "ladder."
6. Once teacher has checked the original DNA, it should be "unzipped" and replicated. One of the daughter models should be hung on the wall or bulletin board.
7. The second daughter DNA should be unzipped and transcribed into two separate strands of RNA. The RNA strands should also then be taped or tacked on the wall.
8. Upon completion of constructions, the group should clean up and sit together to fill out lab report forms, answering all questions to review the work which has been accomplished.

Debriefing: Cooperative exercises should be followed by class discussion focused on the performance of the task groups. How did the group proceed? What decisions had to be made? How? Who had good ideas? What behaviors were helpful/unhelpful? Did everyone participate? Collect and grade the lab reports to verify content learning in the lesson. Save the models of DNA and RNA for a follow-up session in which the same teams will have a chance to use their RNA to sequence proteins in simulated ribosomes.

Lesson Plan 4. Lecture Notes: Comparative Scale of Genome

A full page illustration (in miniature below) can be easily converted into an overhead transparency to assist students in grasping the scale of the genome mapping project.

"Mapping" the human genome is a huge task which involves determining the sequence of some 3 billion base pairs in a single cell. The number of base pairs of DNA can be thought of as roughly equal to the total number of people on earth. Thus, if a physical map could be drawn showing the identity and location of each living person on earth, this mapping feat would be comparable in scale to what molecular biologists hope to accomplish in the next 15 years with the genome.

Using the single *cell-earth* and base *pairs-people* scales, *chromosomes* (50 to 250 million base pairs each) are analogous to countries, and genes (thousands to millions of base pairs) to *towns* . Between chromosomes and genes in size are chromosome fragments (1-50 million bp) and on the comparative scale a *fragment* is analogous to a *county* .

(figure available in print form)

FIGURE LP-1: Comparative Scale of Genome Mapping

(Courtesy of U.S. Congress, Office of Technology Assessment. Mapping Our Genes — The Genome Projects: How Big, How Fast? . OTA-BA-373)

If students can begin to grasp the scope of the genome project in these terms, they may understand why it will take so long and why emerging technologies for automatic sequencing of portions of DNA are so useful. Questions should be raised for further exploration and discussion: Is the genome project "big science" in the classic sense of the Manhattan Project and Moon Landing of previous decades or the Superconducting Supercollider of this decade? Is the genome project worth the estimated cost of 3 billion dollars? A little research will quickly uncover strong arguments for either side of this question and an interested group of students might enjoy staging a debate on this topic for the class.

Lesson Plan 5: "Paper Clip Plasmids"

(A Hands-on Investigation of Recombinant DNA technology)

Although this activity is intended for students who have a good grasp of genetics, including information transfer, DNA, RNA, and the genetic code, it can also be presented to introduce students to the concepts of DNA and RNA molecular formation by pairing of bases. The manipulation of colorful chains of paper clips ("pop-beads" make an appealing substitute), following of directions to construct a letter-color "code," removing a short sequence of code, and figuring out how to attach a portion of DNA strands to a plasmid ring may provide graphic illustration which will lead to further curiosity and inquiry as the cognitive understanding develops. And besides, it is fun!

Complete instructions for this lesson, far too extensive to be printed in this unit, are available in the flyer, "National Science and Technology Week '88: Genetic Engineering: from the Industrial Biotechnology Association," 1625 K Street, N.W., Suite 1100, Washington, D.C. 20006; or (202) 857-0244. Materials can be obtained from any stationery store for less than ten dollars. For advanced students or a special project, this lesson is highly recommended.

Video Resources: "Creation, Evolution, and the Human Genome"

(In just a short time since the compilation of these suggested resources, I have discovered that nearly all of the NOVA and Smithsonian videos can be obtained through public library loan systems. The Hawkhill Videos can be rented or purchased from Hawkhill Associates, Inc., 125 East Gilman Street, Madison, Wisconsin 53703. Both the feature films—"Inherit the Wind" and "Race for the Double Helix"—can now be obtained from several of the larger chains of video rental stores.)

"Tales of the Human Dawn." Smithsonian World, 60 min., 1990.

Search for human origins, chiefly through fossil and bone studies; excellent timeline of hominid ancestors.

"Children of Eve." NOVA, 60 min., 1990

The case for human and ape divergence based on DNA studies; review of Sarich's and Wilson's molecular clock hypothesis.

"The Gene." Hawkhill Videos, 60 min., 1989.

Two 30 minute segments, one on the history of genetics, the other on genes and how they work. Good basic information and illustrations of DNA and genetic engineering.

"God, Darwin, and Dinosaurs." NOVA, 60 min., 1989.

Documents the creation-evolution controversy and uses the debate to explore the question, "What is science?"

"Evolution." Hawkhill Videos, 60 min., 1989.

Human evolution and family trees as seen primarily by paleoanthropologists. Interviews with Louis Leaky, Jane Goodall, and others on their field studies.

"Decoding the Book of Life." NOVA, 60 min., 1989.

Explanation of DNA as the code for all life; excellent graphics showing unwinding of DNA molecule to examine and explain base pair sequences.

"Inherit the Wind." (feature movie) 120 min.

Two versions of this movie have been made based on the play about the famous 1925 Scopes Trial. The original starring Spencer Tracy is excellent, but students may prefer the somewhat more recent remake. Good entertainment for those interested in the trial and its dramatic development.

"Race for the Double Helix." A&E Films, 106 min., 1987.

First produced by BBC as "Life Story," this film portrays the discovery of the structure of DNA. Jeff Goldblum plays a rather manic Jim Watson, and Tim Pigott-Smith plays Francis Crick. In reviewing the film himself, Crick said that "it certainly gets [across] the obvious fact that scientific research is performed by human beings, with all their virtues and weaknesses." Enjoyable, but students are apt to find it a bit slow paced and heavily laced with science dialogues.

Notes

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1. Gilbert and M.D. Lemonick, "Greatest Unanswered Questions of the 20th Century," 34-61.
2. Mark Twain, *Adventures of Huckleberry Finn* , 121.
3. P. Dunne, "Dissent, Dogma, and Darwin's Dog," 84
4. R.L. Herrmann, "Coping With Creation/Evolution," in *Teaching Science in a Climate of Controversy* , 9-12.
5. P. Dunne, op. cit.
6. D.M. Raup, "Evolution and the Fossil Record," 289.

7. E.J. Larson, *Trial and Error: The American Controversy over Evolution and Creation* , 18.
8. R.L. Herrmann, *op. cit* ., 8.
9. S.J. Gould, "Evolution, Extinction and the Movies," 19.
10. *Ibid* .
11. W.V. Mayer, "Evolution: Yesterday, Today, Tomorrow," in *The Humanist* , 16.
12. *Ibid* .
13. from general historical information in M. Bramwell, *Understanding Evolution* .
14. W. Mayer, *op. cit* .
15. Quoted in James Rachels' *Created From Animals* , as cited in review by Robert Wright, "The New York Times Book Review," (July 29, 1990): 27.
16. See bibliography for recent *Newsweek* and *Discover* articles.
17. M. Edey and D. Johanson, "Lucy." in *The Beginnings of Mankind* , 51-54.
18. W. Mayer, *op. cit* .
19. J. Darnell, H. Lodish, D. Baltimore, *Molecular Cell Biology* , 11.
20. *Ibid* .
21. J. Shreeve, "Argument over a Woman," in *Discover* , 54.
22. *Ibid* ., 52.
23. F. Crick. *What Mad Pursuit* , 61.
24. *Human Genome 1989-90 Program Report* , 122.
25. M. Seashore, "The Human Genome," (Lecture) *Yale-New Haven Teachers Institute* , April 3, 1990.
26. *Human Genome Program Report* , p.124.
27. U.S. Congress, Office of Technology Assessment. *Mapping Our Genes—The Genome Projects: How Big, How Fast?* , OTA-BA-373, U.S. Government Printing Office, Washington, DC. April, 1988.
28. *Ibid* .
29. *Ibid* .
30. *Ibid* .
31. S.J. Gould, *op. cit* .

Annotated Bibliography

(* indicates that the listing is recommended all or in part for students)

*Baskin, Y. *The Gene Doctors — Medical Genetics at the Frontier* . New York: William Morrow and Company, 1984. Provides an overview of gene therapy and the technology which will literally shape human futures. Conveys the drama of men and women at the frontiers of science.

* *Biological Science — A Molecular Approach* , Sixth Edition. Lexington: D.C. Heath, 1990. Produced by the Biological Sciences Curriculum Study (BSCS), this should be in every classroom as a reference if not the standard high school text. It is readable, well-illustrated, and filled with a wealth of valuable teaching ideas and research suggestions.

Bowler, P. J. *Evolution-The History of an Idea* . Berkeley: University of California Press, 1984. History of science, good information about Darwin and the impact of his ideas on later scientists and thinkers.

*Bramwell, M. *Understanding Evolution* . London: Usborne Publishing Limited, 1983. Simply written summary of historical facts about evolution.

*Cantor, C.R., and Smith, C.L. "Mapping the Genome." In *Biotechnology and the Human Genome: Innovations and Impact* , edited by A.D. Woodhead and B.J. Barnhart, 11-28. New York: Plenum Press, 1988. One of the best articles in this collection; provides excellent overview of the genome mapping project scope, goals, implications for the future. Technical, but worth having students struggle with.

*Crick, F. *What Mad Pursuit* . New York: Basic Books, 1988. Crick's account of the discovery of DNA, a companion piece to Watson's earlier version. Filled with amusing anecdotes and quotable quotes as he reflects on the nature of the discovery and its significance. If you are more interested in the story than the scientific details, he even tells you which chapters to skip! (But don't!)

Darnell, J., Lodish, H., and Baltimore, D. *Molecular Cell Biology* . New York: Scientific American Books, 1990. Used as a graduate text, this book provides a brief history of molecular biology and very detailed information along with excellent color illustrations.

*Dawkins, R. *The Selfish Gene* . New York: Oxford University Press, 1976. Explanation of animal behavior and morphology by postulating the role of genes. An early attempt to bridge the old morphological and new molecular thinking in evolution.

*Dunne, P. "Dissent, Dogman, and Darwin's Dog." In *Time* (15 January 1990): 84.

*Dyson, F. *Origins of Life* . New York: Cambridge University Press, 1985. Delivered as a lecture series, this brief text is first a history of theories and experiments concerned with the origin of life and second the attempt of a new hypothesis that "life began twice"—once with non-replicating cells, and later with genes which originated as parasites infecting the cells.

Edey, M.A. and Johanson, D. "Lucy." In *The Beginnings of Mankind* , Edey and Johanson, 51-54. New York: Simon and Schuster, 1981. The thrill and excitement of finding a unique hominid fossil is told in a lively story.

Eiseley, L. *Darwin's Century* . New York: Doubleday, 1961. A classic historical treatment of evolutionary developments in geology, biology, anthropology, and Western intellectual thought.

Eldredge, N. *Time Frames* . New York: Simon and Schuster, 1985. Very readable account of how a modern paleontologist views evolution. Eldredge works with trilobite fossils and draws his conclusions from field and lab research wholly different from that of molecular biologists.

*Gilbert, S. and Lemonck, M.D., "Greatest Unanswered Questions of the 20th Century." In *Science Digest* , v.93, no.10 (1985): 34-61. Twenty questions and short, provocative articles.

*Gould, S.J. "Evolution, Extinction and the Movies." In *Time* (14 May 1990) 19. Interview with the renowned paleontologist.

*Gould, S. J., *Wonderful Life* . New York: W.W. Norton and Company, 1989. Discusses the nature of history and evolution using Burgess shale formation in Canadian Rockies as his reference point. Fossils from this shale reveal a whole diverse line of organisms which reached an evolutionary dead end. Reflections on Darwinian theory of selection by the foremost Darwinist of the present in America.

Herrmann, R.L., *Teaching Science in a Climate of Controversy* . Ipswich: American Scientific Affiliation, 1986. Published by a dedicated group of "Christian scientists" seeking open dialogue on evolution and creation.

*Hsu, K. J., *The Great Dying* . New York: Harcourt Brace Javanovich, 1986. Presents the theory of cosmic collision 65 million years ago which caused dinosaurs and nearly all plant and animal organisms on earth to perish. Implications for evolution are dramatic. Hsu does field research in deep sea beds and geologic sites.

Judson, H.F., *The Eighth Day of Creation* . New York: Simon and Schuster, 1979. Extensive, detailed account of the development of molecular biology with emphasis on discoveries and remarkable scientist who made them.

*Keller, E.F., *A Feeling for the Organism* . New York: W.H. Freeman, 1983. Excellent scientific biography of the life and accomplishments of Barbara McClintock, a female scientist who won a Nobel Prize for her study of corn chromosomes, leading to breakthroughs in understanding of inheritance.

*Lambert, D. *Field Guide to Early Man* . New York: Facts on File Publications, 1987. Excellent diagrams and sketches of human family tree. For fossil finders and bone enthusiasts, this text provides morphological data in simple form.

Lewin, B. *Genes IV* . New York: Oxford University Press, 1990. Latest version of the text used in many graduate school courses on genetics. Thorough, detailed information and illustrations.

*Lewin, R. *Human Evolution — An Illustrated Introduction* . New York: W.H. Freeman, 1984. Collected essays, well illustrated, on the theories and fossil evidence for human evolution. More technical than Lambert's Field Guide, superior graphics.

*Shreeve, J. "Argument Over a Woman." In *Discover* , v.11, no.8 (Aug. 1990): 54. Update on the bones versus genes controversy about traces of human origins.

*Twain, Mark. *Huckleberry Finn* . New York: Signet Books, 1959. The classic Twain with philosophical Huck.

*Wambaugh, J. *The Bloodling* . New York: Bantam Books, 1989. Dramatic true story of the first murder case solved (in England) by use of "genetic fingerprinting." The pace lags a bit and DNA fingerprints are not adequately explained, but this is a classic tale with significance for modern forensics and law enforcement.

*Watson, J.D. *The Double Helix* . New York: Signet books, 1968. Watson's personal account of the discovery of the structure of DNA. Lively, brash, opinionated, this account will make scientists come alive for students. Crick's version, 20 years later, is a much more reasoned and mellowed one.

Mapping Our Genes — The Genome Projects: How Big, How Fast? U.S. Congress, Office of Technology Assessment, OTA-BA-373, Washington, D.C.: 1990.

The Human Genome, 1989-90 Program Report . U.S. Department of Energy. Office of Energy Research and Office of Health and Environmental Research, Washington, D.C.: 1990.

Two excellent reports on the progress of the government sponsored genome mapping effort. These first reports provide a great deal of educational material and superb, usually non-copyrighted illustrations. Regular reports are mailed out on the project free to those who request them—it is worth getting on the list if you expect to teach topics in biology or genetics in the next few years.