# Lecture Notes for Biology 101:

# An Introduction to Science and Biology for Non-Majors

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## Course Outline

The organization of this course has been driven by the goal of providing non-majors with a coherent picture of modern biological knowledge. To accomplish this goal it's necessary that each student gains an appreciation of the nature of science and is introduced to the integrated view of our world that modern science has produced. To facilitate this the course is divided into four parts.

## Part One: The Nature of Science

There are three elements in defining science: 1) the values of science, 2) science as a profession, and 3) the product of science—scientific knowledge. Using this definition, the goal of Part One is to introduce the fundamental nature of the scientific enterprise.

Major Units: Defining Science
The Epistemic Values of Science
The Origin of Modern Science
Science as a Profession

## Part Two: The Conceptual Framework of Biology

The goal of Part Two is to introduce the conceptual framework of modern biology. Evolution and historical systems provide the conceptual framework or paradigm for understanding modern biology. But a basic understanding and appreciation of molecular biology is also necessary before we can begin to integrate all of biological knowledge.

Major Units: Cosmological Evolution
Natural Levels of Organization in the Physical World
Biological Evolution
Life as a Chemical Function—Biochemistry & Genetics
The Modern Synthesis—Darwin and Mendel

## Part Three: The Integration of Biological Knowledge

The purpose of Part Three is to show how biological knowledge can be integrated into a coherent picture of life on Earth. Because life on Earth is an effectively closed historical system, we must understand that biology is an historical science. One result of this is that a chronological narrative of the history of life provides for the integration of all biological knowledge.

Major Units in Part Three: The Integration of Biological Knowledge

- Geologic Time
- The Origin of our Solar System
- The Origin of Life
- Photosynthesis
- Aerobic Respiration
- Endosymbiosis & Eukaryotic Cells
- The Classification of Life
- Sexual Reproduction
- Multicellularity
- Adaptive Radiations & Mass Extinctions
- Vertebrate Evolution
- Human Evolution

## Part Four: Biology and Society

Part Four attempts to show how modern biological knowledge directly affects the important social, ethical issues of our times.

Major Units:
- Science & Ethics
- Human Population Growth
- The Sixth Extinction
- Why do science?

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The material that follows is taken from the lecture notes used in this course. It is hoped that by having them you will be able to concentrate on the verbal presentation of this material. However, **these notes do not contain the copyrighted material that will be presented in lecture**. For quizzes and tests you are responsible for all the material that is presented. Therefore, if you wish to do well in this course, you must attend the lectures.

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## Part One: The Nature of Science

## Unit One: Defining Science

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### What is science?

What is it that makes science different?

And different from what?

Is there a scientific method?

And if so, a method for doing what?

What does the general public think about science? Is it good or bad?

Why does our society support science?

Could we do without science?

If not, what do we get by doing science?

Why do science?

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• **Note:** All indicators point to widespread support for government funding of basic research. The 2002, NSF survey of American adults found that **72%** believe that the benefits of scientific research outweigh the harmful effects. In contrast, only **33%** of Americans surveyed understand the nature of scientific inquiry well enough to make informed judgments about the scientific basis of results reported in the media (NSF, 2002).

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### Defining Science

1) As a set of rules for how to look at the world—

Epistemic Values

2) As a very human activity with all of the attendant failings—

Science as a Profession

3) As the product of the activity of science—

Scientific Knowledge

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## A Legal Definition of Science

Judge William R. Overton 1982:
McLean versus the Arkansas Board of Education

"A descriptive definition was said to be that science is what is 'accepted by the scientific community' and is 'what scientists do.' The obvious implication of this description is that, in a free society, knowledge does not require the imprimatur [approval] of legislation in order to become science."

This ruling was upheld by the Supreme Court in 1987.

**Note**: A corollary to this ruling is that what qualifies as scientific knowledge is not decided by political majority vote, either at the level of local or state school boards, or by state or federal legislation.

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## Unit Two: Epistemic Values

**Introduction:** In trying to answer the question, "What is it that makes science different?", we must examine the values of science as a human endeavor. The first step in doing so is to understand the relationship between worldviews and values.

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## Worldviews, Values, and Decision-making

A worldview is our mental model of external reality. It consists of theories about the processes that operate in the external world or how the world works; theories as to the state of external reality or how the world is; theories of self-identity that are derived from our mental model of the world; and a set of values derived from our self-identity that assigns priorities in decision-making.

From these elements we build an image of how the world came to be and our place in that world. This image of our personal identity determines what we consider of importance in determining our behavior—our values.

Griffiths gives this picture of what a worldview is and does. "Our view of the universe is built up slowly from input acquired since the beginning of consciousness. This viewpoint represents our identity as individuals. It drives our attitudes and our actions and, as such, determines the kind of people we are and ultimately the kind of society we have."—Griffiths, 1991

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## The Cultural Transmission of Worldviews

- Are worldviews passed from generation to generation?

- If they are, then is the particular worldview that an individual has just an accident of birth?

## Primary and Secondary Socialization

The problem with primary and secondary socialization is that they entail the uncritical acceptance of beliefs. The problem isn't so much what you receive in the way of beliefs; it's that you didn't have a choice in whether or not to accept them.

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"Our parents' teachings are naturally subject to review as a result of subsequent cultural influences. There is, however, a mechanism that renders some areas of parental teaching particularly effective: humans' greater sensitivity to certain influences during the early years of life. There are critical periods in psychological development during which cultural influences leave indelible traces..." "This mechanism, known as **imprinting**, is especially strong in animals."—Cavalli-Sforza, 1981 & 1995, 210

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## Self-Autonomy

Our worldviews determine our values, which, in turn, determine how we choose between different courses of action—our decision-making. It is, therefore, extremely important that we analyze our personal worldviews in the light of what we learn about the world as adults. In doing so we achieve self-autonomy.

**To be a scientist requires self-autonomy.**

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## Science and Epistemic Values

"Against the background presumption that our aim is to understand the world of experience, a world of unbroken regularity, these values are tools or standards that we cherish, since 'they are presumed to promote the truth-like character of science, its character as the most secure knowledge available to us of the world we seek to understand' Hence, an 'epistemic value is one we have reason to believe will, if pursued, help toward the attainment of such knowledge'"—Ruse, 1996

"We want knowledge that is reliable, public, and universal, based upon unambiguous, reproducible experience that is (or can be) common to all of us—in a word, knowledge that is scientific."—Raymo, 1998, 23

## Terms and Definitions to Know

- **Epistemology**—the systematic investigation of the origin, nature, methods, and limits of human knowledge. It attempts to answer the question: "How does the human mind perceive and know what is outside itself?"—Bronowski, 1960, 200

- **Descriptive**—that about a phenomena that can be proven or verified by experience or experiment; descriptive statements are empirical observations subject to scientific verification.

- **Descriptive Epistemology**—empirical observations on how we actually view the world.

- **Prescriptive**—that which gives direction or rules; prescriptive statements are statements of what we should do to achieve specific goals.

- **Prescriptive Epistemology**—rules for how we should view the world that are based upon more fundamental epistemological assumptions.

- **Epistemic Values**—are prescriptive epistemological values that serve in achieving a specific goal. In science that goal is to produce reliable knowledge of the natural, physical world.

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- **Point:** Science is set apart from other human endeavors by the epistemic values it accepts.

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## The Epistemic Values of Science—A Short List

1) Only those claims to knowledge where the underlying physical causes of a phenomenon have been shown can be accepted by science. This requirement that the cause and effect mechanism that produces a phenomenon must be demonstrated is called **skepticism**. Methodological skepticism requires that all underlying assumptions of a claim to knowledge be identified and their validity questioned. The philosopher David Hume in his *Treatise on Human Nature* (1740), is credited with being the first to show the importance of skepticism in epistemology.

2) Only knowledge claims based upon **physical evidence** can be a part of science. The corollary of this is that all knowledge claims based upon authority alone must be rejected. Personal beliefs do not support claims to knowledge in science. This reliance on physical evidence is closely tied to the rejection of the "scholastic tradition" of accepting the word of authority as absolute truth, which began in the Renaissance and continued on through the Reformation with the rejection of the authority of the Catholic Church.

3) **Prediction** by itself is insufficient to support knowledge claims. Correlation by itself fails to link cause to effect. What is needed is an understanding of the mechanism by which a given phenomenon is produced. This is reflected in science by the value placed on skepticism. But if prediction is combined with a **coherence** to the sum of our reliable knowledge of the physical world, successful prediction in science does support knowledge claims.

4) **Coherence** is the logical connections between the elements of a set of concepts and facts; the degree of coherence that a set of concepts and facts has is a measure of its internal, logical consistency. In science all concepts and scientific facts must cohere to all other scientific facts and concepts; they must be both internally and externally, logically consistent.

5) **Consilience**, as a property of scientific theories, increases the reliability of scientific claims to knowledge. The degree that a scientific theory has consilience is a measure of its ability to explain and unify many separate and seemingly unrelated areas of scientific study. Consilience presupposes the unity of knowledge that follows from the assumptions of realism. That is, if there is only one real world, then all true knowledge will be coherent and contribute to understanding that world. The term consilience was first used by William Whewell in 1840.

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## Unit Three: The Origin of Modern Science

**Introduction:** It is difficult to understand how profound a revolution the origin of modern science was unless we understand how dramatic a change it represents from the medieval worldview. The following essays are included, therefore, to provide a picture of the medieval view of reality.

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### Essay—The Medieval Worldview and Augustine the Bishop of Hippo

"After the fall of the city of Rome to the barbarians in A.D. 410, it seemed to the rest of the Roman empire that darkness and death were inevitable. Augustine, the Christian Bishop of the north African Roman province of Carthage, was deeply affected by the fall of Rome. His reaction to the pessimism of the times was to offer a way of escape. Augustine was influenced by Plato's philosophy which drew a distinction between reality and appearances as well as between opinion and knowledge. The everyday world of the senses was worthless because it was only a shadow of reality, a product of opinion. True knowledge lay in the mind and consisted of the pure, ideal forms [this is Platonic essentialism]. By implication, everything in the daily life of the Platonist Christian was a shadow of the truth. The miseries and trials he had to suffer were transient, as was all else in the world. The human body itself was a shadow. Only the soul was real, escaping its temporary and irrelevant prison of flesh at death to return to heaven, the ideal world, from which it had originally come.

Augustine combined these views with the teachings of the Scriptures in a book called *The City of God*. This work, which offered a complete set of rules for living and an integrated structure for Christian society, was to influence Christian thinking for a thousand years. Augustine offered escape to a spiritual life in the monasteries. If the world was not worth study, deserting it for a life of contemplation could only be for the good. Belief was more important than earthly knowledge. *Credo ut intelligam* (understanding comes only through belief) was the creed which would see the monasteries through the Dark Ages that lay ahead."—Burke 1985, 20

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## Essay—Life in Medieval Europe

“Contemporary references reveal the people of the time to have been excitable, easily led to tears or rage, volatile in mood. Their games and pastimes were simple and repetitive, like nursery rhymes. They were attracted to garish colors. Their gestures were exaggerated. In all but the most personal of relationships they were arbitrarily cruel. They enjoyed watching animals fight and draw blood.

Much of their life was led in a kind of perpetual present: their knowledge of the past was limited to memories of personal experience, and they had little interest in the future. Time as we know it had no meaning. They ate and slept when they felt like it and spent long hours on simple, mindless tasks without appearing to suffer boredom.

The medieval adult was in no way less intelligent than his modern counterpart, however. He merely lived in a different world, which made different demands on him. His was a world without facts. Indeed, the modern concept of a fact would have been an incomprehensible one.

Medieval people relied for day to day information solely on what they themselves, or someone they knew, had observed or experienced in the world immediately around them. Their lives were regular, repetitive and unchanging.

There was almost no part of this life-without-fact that could be other than local. Virtually no information reached the vast majority of people from the world outside the villages in which they lived. When all information was passed by word of mouth, rumor ruled. Everything other than personal experience was the subject of hearsay, a word which carried little of the pejorative sense it does today. What medieval man called ‘fact’ we would call opinion, and there were few people who traveled enough to know the difference. The average daily journey was seven miles, which was the distance most riders could cover and be sure of return before dark.”—Burke, 1985, 91-92

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## Essay—Scholasticism

One of the central epistemic prescriptions of science is that only knowledge claims based upon physical evidence can be supported. Its obvious corollary is that all knowledge claims based upon authority alone must be rejected. This is the rejection of the medieval “scholastic tradition” of accepting the word of authority as absolute truth.

The scholastic tradition or scholasticism was “the system of theological and philosophical teaching predominant in the Middle Ages, based chiefly upon the authority of the church fathers.” (Webster’s, 1989). The first significant figure to challenge that tradition was Pierre Abelard (1079-1142), French scholastic philosopher, teacher, and theologian. His love affair with Heloise is one of the famous romances of history.

In his work *Sic et Non* (For and Against), Abelard was the first to apply the dialectic use of logic to the Holy Scriptures. “Until the time of Abelard a statement by an accepted authority had sufficed for proof. Abelard showed that these authorities were contradictory. Though he claimed that his attack on authority aimed only at finding the truth, the Church did not approve. When he said, ‘By doubting we come to enquiry; by enquiring we perceive the truth,’ Rome heard the voice of a revolutionary. Abelard laid down four basic rules for argument and investigation:

> Use systematic doubt and question everything.
>
> Learn the difference between statements of rational proof and those merely of persuasion.
>
> Be precise in the use of words, and expect precision from others.
>
> Watch for error, even in Holy Scripture.

Statements like these were quite extraordinary in the twelfth century. Objectivity, detachment and unprejudiced, unemotional ratiocination were rare to the medieval mind, steeped as it was in mystery and dogma."—Burke, 1985

Today the scholastic tradition lives on in both the humanities and theistic religions. The following example is from Pope John Paul's 13th encyclical. I quote from Chapter III *Intellego ut Credam*, Section 33:

"Such a truth [absolute truth] ... is attained not only by way of reason but also through trusting acquiescence to other persons who can guarantee the authenticity and certainty of the truth itself."—Stanley, 1998

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- **When did modern science originate?**
- **Where did modern science originate?**
- **Why did it happen?**

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## The Origin of Modern Science

The origin of modern science can be established by locating when the shift toward the epistemological values of modern science began. This shift in values has been defined most clearly by the late Jacob Bronowski.

"I hold that the scientific revolution from 1500 onward was an essential part of the Renaissance. Since that time we have been in the unique position of trying to form a single picture of the whole of nature including man. That is a new enterprise; it differs from the preceding enterprises in that it's not magical, by which I mean that it does not suppose the existence of two logics, a natural logic and a supernatural logic. If one had to put a date to this, [the origin of modern science] one would say that roughly speaking between 1500 and the publication of Porta's book in 1558, which was called *Natural Magic*, the turning point took place."—Bronowski, 1978

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“It is possible to justify any experience by natural causes and natural causes only. There is no reason that could ever compel us to make any perception depend on demonic powers. There is no point in introducing supernatural agents. It is ridiculous as well as frivolous to abandon the evidence of natural reason and to search for things that are neither probable nor rational.”

Pomponazzi of Padua from his book *Of Incantations* (1520)

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**Note:** In sixteenth century Europe statements like this could get you in trouble—a lot of trouble.

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“When Giordano Bruno asserted that matter ‘is in truth all nature and the mother of all living things’ he was arrested and, after an eight year trial, tied to an iron stake and burned alive by the Catholic Church on February 17, 1600, in the Piazza Campo dei Fiori in Rome.”—Ferris, 1988

“In 1633, Galileo was condemned to house arrest by the Catholic Church for his book *The Dialogue on the Two Chief Systems of the World*. He remained under arrest until his death in 1642. His book was placed on the Index of Prohibited Books and remained there until 1835.” —Burke, 1985

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## Peeling the Chinese Onion: Why Science originated in Europe and not China

“In no society, Eastern or Western, Chinese, Roman, medieval, or contemporary, have science and rational speculation long survived the imposition of absolute dogma—religious or social.”—Bronowski, 1977

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## Science and the Reformation

The beginning of the Reformation in 1517, is marked by Martin Luther nailing his Ninety-Five Theses to the door of the Wittenberg Church in Saxony, signaling his rejection of the authority of the Catholic Church. The Reformation, like the Renaissance, was born in the fold of small independent states such as Saxony. Indeed, without them, it could not have survived.

Like the humanists, the Reformers were opposed to life in the monastery and were thoroughly committed to life in the world. The culture roughly described as humanist which gave rise to much of our modern world including modern science, and the Reformation, arose as authority of the Catholic church ebbed. Both movements were movements of emancipation, drawing their inspiration and their legitimacy from an earlier period. In their recasting of values, and their attempt to shape new views of man, the humanists and Reformers were akin, but their visions of life and of human capacity and their sources of authority were quite different.

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• **Note:** Henry VIII rejected the authority of the Pope and founded the Church of England in 1534.

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## Time Line for the Epistemic Values of Science

**1130**—Pierre Abelard writes the book *Sic et Non*

**1520**—Pomponazzi of Padua writes *Of Incantations*

**1620**—Francis Bacon "we cannot command nature except by obeying her"

**1662**—the founding of the Royal Society in England with their motto (roughly translated from Latin ) "Take nobody's word for it; see for yourself"

**1740**—David Hume on skepticism in *Treatise on Human Nature*

**1840**—the work of William Whewell on the *Consilience of Inductive Sciences*

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• **Note:** The shift in epistemic values that produced modern science occurred first and more than 300 years before science became a profession.

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## Survival Value & Control

In answer to the question, "What do we get by doing science?", we have the following.

For science to exist we must want to know; we must really want to know. We must be willing to give up all our preconceived notions and beliefs and **let nature be the final arbitrator of truth**. The tradeoff is that there is tremendous survival value in having reliable knowledge about our world. With it comes control over nature and for the first time in human history we are no longer at the mercy of an indifferent universe.

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• **Point:** The goal of science, as a human endeavor, is the production of reliable knowledge about the natural, physical world. This goal, in turn, through a spontaneous process of trial and error in the history of science, has determined the modern epistemic values of science.

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**"Science is a long history of learning how not to fool ourselves."**

Richard Feynman

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## Unit Four: Science as a Profession

"The known is finite, the unknown infinite: intellectually we stand on an islet in the midst of an illimitable ocean of inexplicability [a limitless sea of ignorance]. Our business in every generation is to reclaim a little more land, to add something to the extent and solidity of our possessions."

Thomas Henry Huxley written in 1887

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"Donald T. Campbell, one of the most respected philosophers of science of this century, had a vision of science in which flawed, venal people together yield the noblest of products. His hypothetical realism [his philosophy] is addressed to those with faith that science edges towards truth, and shows us how—via variation and selective retention, and competition among the cooperators—ego-involved, over-committed, and under-informed mortals could bring this about."—Heyes, 1997

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- **What is the history of professional science?**
- **How is it organized today?**
- **How does it operate to produce reliable knowledge?**

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### The Organization of Modern Science

**• The University Connection**

Foundations & Institutes—NSF, NIH, Salk, Max Planck
Societies—AAAS, NAS
Journals—*Nature, Science*

**The Reward System**
(research / publish—peer reviewed journals / grants / promotions / prizes)

**Science as a Self-Correcting System**
(You are rewarded for finding mistakes as much as you are for making new discoveries.)

**• The Corporate Connection**

The Rise of Biotechnology
Fundamental as opposed to Directed or Applied Research

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## How can we define who is a professional academic scientist?

"By statured scientists I mean those who collect and analyze the data, build the theoretical models, interpret the results, and publish articles vetted [peer reviewed] for professional journals by other experts, often including their rivals."—from *Consilience: The Unity of Knowledge* by E. O. Wilson (1998)

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## Professional Science can be divided as follows:

- **Academic and Institutional Science**—consists of those scientists working in public and private institutions such as universities and institutes where the major funding for research is public monies. Publishing results in peer reviewed journals is a central goal of this research.

- **Corporate or Industrial Science**—consists of those scientists working for private companies or corporations where funding is provided by private investment. Publishing results is not a goal of this research.

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## Both Academic and Corporate Science can then be divided into:

- **Fundamental or Pure Research** is driven by the goal of discovering new knowledge without regard to the direction the research might take.

- **Directed Fundamental Research** has a predetermined goal that only can be achieve by the discovery of new knowledge. The cure of specific diseases such as cancer is an example of such research.

- **Applied Research** takes existing scientific knowledge and applies it to develop new technological applications. The development of computer software produces no new scientific knowledge and yet is central to developing new applications of our existing scientific knowledge of electronic computing. Applied research is done by both professional scientists and engineers.

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Excerpt from

## The Demon-Haunted World: Science As a Candle in the Dark

by Carl Sagan (1996)

“Science may be hard to understand. It may challenge cherished beliefs. In the hands of politicians or industrialists, it may lead to weapons of mass destruction and grave threats to the environment.

But one thing you have to say about science: It delivers the goods. If you want to know when the next eclipse of the Sun will be, you might try magicians and mystics, but you’ll do much better with scientists. They can tell you within a fraction of a second when an eclipse will happen decades or centuries in the future, how long it’ll last and where on Earth you should be standing to get a good look. If you want to know the sex of your unborn child, you can consult astrologers or plumb-bob danglers all you want, but they’ll be right, on average, only one time in two. If you want real accuracy, try science.

What is the secret of its success? Partly, it’s this: There is a built-in error-correcting machinery. There are no forbidden questions in science, no matters too sensitive or delicate to be probed, no sacred truths. There is an openness to new ideas combined with the most rigorous, skeptical scrutiny of all ideas, a sifting of the wheat from the chaff. Arguments from authority are worthless. It makes no difference how smart, august or beloved you are. You must prove your case in the face of determined, expert criticism. Diversity and debate between contending views are valued.

Scientific findings and theories are routinely subjected to a gauntlet of criticism—oral defenses of doctoral theses, debates at scientific meetings, university colloquia punctuated by withering questions, anonymous reviews of papers submitted to scientific journals, refutations and rebuttals. There is a reward structure built into science for finding errors: The more basic and fundamental the error exposed, and the more widely accepted it was, the greater is the reward.

This may sound messy and disorderly. In a way, it is. Science is far from perfect. It’s just the most successful method known, by far, to understand the world. The discipline of science is hard; scientists, being human, don’t always follow the methods of science themselves. Like other people, they don’t especially enjoy having their favorite ideas challenged. But they recognize it as the cost of getting to the truth. And the truth—rather than the confirmation of their preconceptions—is what they’re after.

Wherever possible, scientists experiment. They do not trust what is intuitively obvious. That the Earth is flat was once obvious. That heavier bodies fall faster was once obvious. That blood-sucking leeches cure disease was once obvious. That some people are naturally and by divine decree slaves was once obvious. That the Earth is at the center of the Universe was once obvious. The truth may be puzzling or counterintuitive; it may contradict deeply held prejudices. But, as the history of both science and politics has amply demonstrated, preferring comfortable error to the hard truth is, sooner or later, disastrous.”

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## • How old is professional science?

The creation of a profession from 1662 to 1869

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## Time Line for Science as a Profession

**Mid 1600s**—founding of the Royal Society in England and the Academie des Sciences in Paris

**1665**—first issue of the scientific journal the *Philosophical Transactions* of the Royal Society

**Early 1800s**—"France despite and because of the Revolution, was the first and most vigorous country in offering opportunities for professional scientists, in any sense that we know them today." (Ruse 1996)

**1833**—William Whewell in England coins the term "scientist"

**1869**—founding of the scientific journal *Nature* by T.H. Huxley and friends

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• **Point:** Scientists are "ego-involved, over-committed, and under-informed mortals", but science works because the profession imposes the epistemic values of science on individual scientists.

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• **Note:** T. H. Huxley was the first to forge the connection between professional scientists and public education, i.e. with the training of science teachers and the link to training doctors. Huxley was also an example of the new breed of scientists who relied solely on their income earned as a professional scientist. Darwin, in contrast, was independently wealthy and did all of his research without having a professional position (Desmond 1992 & 1997).

"At the time that the *Origin of Species* was published, Britain was a country desperately in need of reform, as revealed by the horrors of the Crimean War and the Indian Mutiny. Huxley and others worked hard to bring about change, trying to move public perceptions into the 20th century. They reformed education, the civil service, the military, and much else. Huxley's own work was in higher education, and he succeeded best in the areas of physiology and morphology. He realized that to improve and professionalize these fields as areas of teaching and research, he needed clients (a must in all system building). Huxley sold physiology to the medical profession, just then desperate to change from killing to curing. Huxley's offer of a supply of students, ready for specialized medical training, with a solid background in modern physiology was gratefully received. Morphology, Huxley sold to the teaching profession, on the grounds that hands-on empirical study was much better training for modern life than the outmoded classics. Huxley himself sat on the new London School Board and started teacher training courses. His most famous student was the novelist H. G. Wells."—Desmond, 1997

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## Science from the Leading Edge to Reliable Knowledge

### Terms and Definitions to Know

- **Scientific Fact**—a piece of empirically verifiable information presented as having objective reality about the physical world.

- **Scientific Hypothesis**—a guess about processes in the physical world consistent with current scientific knowledge.

- **Scientific Law**—a precise relationship between physical parameters that is believed to hold true in all circumstances. Some examples are Einstein's $E = mc^2$, Newton's 2nd Law of motion $F = ma$, and the Law of Universal Gravitation $F = G \bullet m1\ m2/r^2$.

- **Scientific Theory**—provides understanding of dynamic processes in nature. Scientific theories must cohere to the sum of scientific knowledge and provide empirically verifiable predictions. "In science, theories do not turn into facts through the accumulation of evidence. Rather, theories are the end points of science." (NAS 1998)

- **Scientific Paradigm**—a universally explanatory theoretical structure that provides unity to a field of scientific study. Examples are plate tectonics in geology, general relativity and quantum mechanics in physics, and evolution by natural selection in biology.

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**"Theories are the crown of science, for in them our understanding of the world is expressed. The function of theories is to explain."**—Harré 1986, 168

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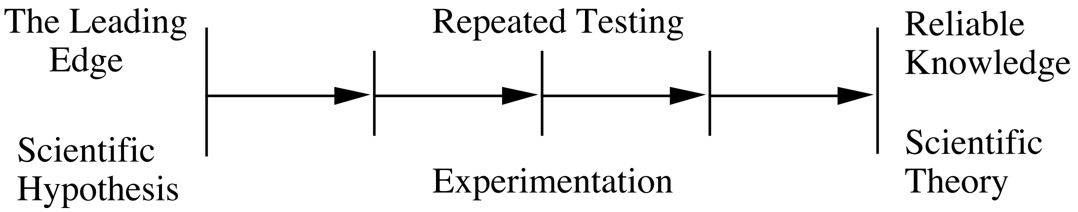

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## Essay—Theory, Hypothesis, and Fact

“Be precise in the use of words, and expect precision from others.”

Science seeks to understand the steps in the dynamic processes that produce what we see in nature. But once we have achieved an understanding of a given process, and once we have repeatedly verified that our explanation is correct, what do we call this explanation? The term “theory” is used in science to describe such an understanding of a given process. And, indeed, the first definition of “theory” in Webster’s dictionary reads, “a coherent group of general propositions used as principles of explanation for a class of phenomena” (Webster’s, 1989).

The term, however, is also burdened with a generic meaning. Webster’s second definition of “theory” is, “a proposed explanation whose status is still conjectural, in contrast to well-established propositions that are regarded as reporting matters of actual fact”. In science this meaning is given to the term hypothesis.

“Hypothesis ... a proposition, or set of propositions, set forth as an explanation for the occurrence of some specified group of phenomena, asserted merely as a provisional conjecture to guide investigation (working hypothesis) or accepted as highly probable in the light of established facts.” (Webster’s, 1989).

The term “fact” as used above is used to express that something is true: “fact ... that which actually exists; reality; truth.” (Webster’s, 1989). But this use of the term “fact” is itself misleading. Are scientific theories just a collection of facts, or are they how a process actually exists; in reality; in truth? It is crucially important to understand that “truth” is defined by the epistemology that an individual or group accepts.

In science the term “truth” is problematic. If the issue is whether science can produce absolute truths, it must be understood that absolute truths require absolute knowledge to prove their validity. In an epistemology that is restricted to physical evidence, such as the epistemology of science, absolute knowledge is not possible as it would require that we were aware of all the phenomena in the universe. This would require a knowledge of all places in the universe throughout all of time—clearly an impossibility. Therefore, without absolute knowledge, all scientific knowledge claims must remain tentative. Scientific knowledge, however, because of the epistemic values of science, remains the most reliable knowledge we have of the physical world.

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## Is there a “scientific method”?

### Reductionism versus Holism?

Reductionism and holism are methods used in science to investigate a phenomenon of interest. To compare the two think of a clock. To understand a clock you have two fundamental choices. You can take it apart to examine its parts and from them try to reason how the clock works, or you can look at the whole thing to see what it does. Reductionism is to take a phenomenon of interest apart to see what it is made of; holism is to view a phenomenon of interest as a whole and see how it functions. The central question, however, is can you use one method without the other?

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• **Point: There is no single scientific method.** "Science can be a process in which practically anything goes—from middle-of-the-night hunches to mathematical formulations driven by classical aesthetics—so long as the results accurately describe and predict phenomena in the real world." (Tyson, 1998b). We must recognize that developing hypotheses is a creative act as much as art or music. Creative thought can occur in almost any fashion, and it is only after a hypothesis is formed that the rigorous process of experimentation and testing can begin. The creative act must come first in science just as it must in the arts.

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## The Unity of Science

Science may be the only spontaneously forming, unified human endeavor in all of human history. It is truly an international community with a common language composed of mathematics, a common literature, and a common nomenclature including standardized metrics; in biology, species names; in chemistry, the periodic table of elements; etc..

Why is this so? Because there is only one physical world out there, thus everyone is studying the same thing using the same rules. And why the same rules—because they work. These rules are the epistemic values of science. If your goal is to understand the natural world, and there is only one natural world, then you must develop a methodology that allows you to "accurately describe and predict phenomena in the real world". The epistemic values of science are what they are because they do just that.

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• **Note:** Scientific knowledge, once produced, exists apart from how it was produced. As Bronowski puts it: "But of course, the facts discovered must not be confused with the activity that discovers them."—Bronowski, 1977

We have now completed the first two elements in defining science, epistemic values and science as a profession, and now turn to the third element, the product of the scientific endeavor — scientific knowledge.

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## Part Two: The Conceptual Framework of Biology

### Introduction

If you look at the sum of scientific knowledge, and that is where we are in our attempt to define science, it is daunting. To make sense of it, we need a conceptual map, as scientific facts, by themselves, explain little. Therefore, what is the theoretical framework that ties this sum of knowledge together?

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### Unit One: Cosmological Evolution

Science at the beginning of the twenty-first century can make some bold,

yet simple observations:

**1. the universe has evolved**

**2. we are a result of that evolution**

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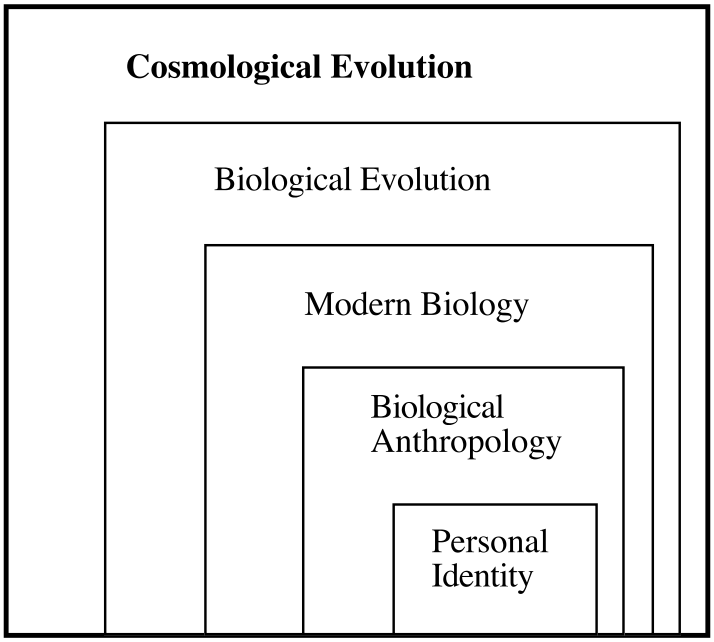
**Increasingly Inclusive Concepts in Science**



The concept of cosmological evolution encompasses all of scientific knowledge and provides a framework on the largest scale for understanding our world.

## Allan Sandage on Stellar Evolution

"The idea that stars change as they age, and that these changes, in turn, alter their local environment and the chemical makeup of their parent galaxy stands in the same relation to astronomy as the Darwinian revolution does to biology. It is a conceptual breakthrough that makes possible the modern understanding of the origin, evolution, and fate of the universe.

We are the product of the stars. This is one of the most profound insights to have arisen out of twentieth-century astronomy. Life is clearly a property of the evolving universe made possible by stellar evolution."—Sandage, 2000

Allan Sandage was codiscover of quasars and the astronomer heir of Edwin Hubble's project to determine the rate of expansion of the universe.

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## Cosmological Evolution and Historical Systems

- To understand cosmological evolution, we must see the universe as an historical system.

- An historical system is one whose past will shape the course of its future.

- Such systems are characterized by a unique chronological sequence of events that gives rise to unique initial conditions in the present.

- System, as used here, is a set of integrated, interacting parts.

- Integrated implies that a system forms from a series of events in the past into a stable entity in the present. Integrated also implies that unordered entities are acted upon by a process that then forms a new and stable entity from these parts.

- A process, in turn, is a sequenced set of changes that transforms something from one state to another.

**Historical systems have the following characteristics.**

1. Change is inherent in historical systems.

2. Historical systems are closed systems where the output of the processes of the system is the only input to the system.

3. Because of this, there is a chronological sequence in which the universe developed.

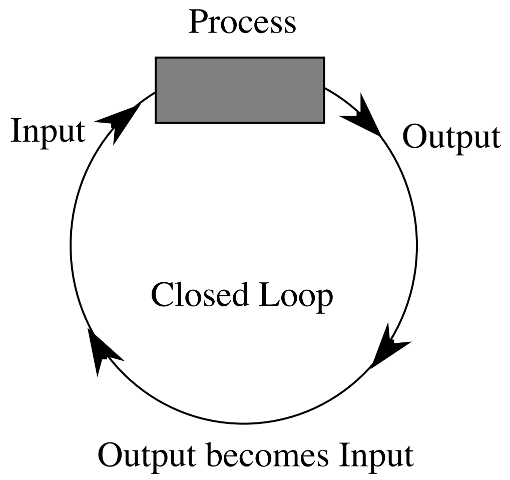
4. As the universe developed, levels of stable phenomena were built upon other, more basic levels.

5. These levels of stable phenomena have accumulated through time.

6. Life on Earth is one of these natural levels of stable phenomena.

5. Because historical systems evolve, evolutionary processes can explain the development of all these levels.

Cause and Effect in a Closed System



• **Point:** The universe is a closed, historical system. The fundamental process that produces change in the universe is its expansion, and, indeed, the universe has evolved through time. The history of life on Earth is but a small part of that evolution and the processes that produced life on Earth are one and the same as those for the universe itself. Biological evolution is only a part of the larger phenomenon of the evolution of the universe.

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## Natural Levels of Organization in the Physical World

Natural hierarchical levels of organization or “levels of stability” (Bronowski 1977) are inherent in historical systems. A natural hierarchical level is defined by the occurrence of a new, novel and stable phenomenon that increases the level of causal complexity of the system enough to give rise to a new level of spontaneous self-organization. These levels are characterized by their stability through time and can be identified by the following features:

**1. a unique scale in size — “on being the right size”**

**2. a new spontaneous organization of matter or “self-organization”**

**3. new emergent properties or processes — “more than the sum of the parts”**

The following is a partial list of stable hierarchical levels of organization in nature, admittedly, as seen from a biologist's point of view.

### The Quantum Level (origin ~ 1 x $10^{-32}$ second after time zero)

1) Scale in size - 1 x $10^{-35}$ meter (Planck's length) to 1 x $10^{-16}$ meter
2) Self Organization - by ~ 1 x $10^{-12}$ second after the Big Bang radiation had cooled enough to form quarks (this is the "Quark Soup")
3) Emergent Properties & Processes - matter forms from energy

### The Sub-Atomic Level (origin ~ 1 second after time zero)

1) Scale in size - 1 x $10^{-15}$ to 1 x $10^{-10}$ meter
2) Self Organization - at ~ 1 second after the Big Bang the universe had cooled enough for quarks to form protons; electrons to form from radiation; and protons and electrons to interact to form neutrons
3) Emergent Properties & Processes - formation of the first atomic nuclei

### The Atomic Level (origin ~ 400,000 years after time zero)

1) Scale in size - one ten billionth of human scale or 1 x $10^{-10}$ meter
2) Self Organization - protons capture electrons and form the light elements hydrogen and helium
3) Emergent Properties & Processes - primary or **Big Bang nucleosynthesis**; the properties of the elements hydrogen and helium; decoupling of matter and radiation; and the origin of the cosmic microwave background radiation

### The Molecular (origin ~ 200 million years after time zero)

1) Scale in size - one billionth of human scale or 1 x $10^{-9}$ meter
2) Self Organization - formation of first stars, formation of the heavy elements; formation of molecules by electromagnetic forces
3) Emergent Properties & Processes - production of heavy elements in stars—secondary or **stellar nucleosynthesis**; all the properties of molecules as opposed to elements—complex chemistry is now possible

### The Prokaryotic (origin ~ 4000 million years ago)

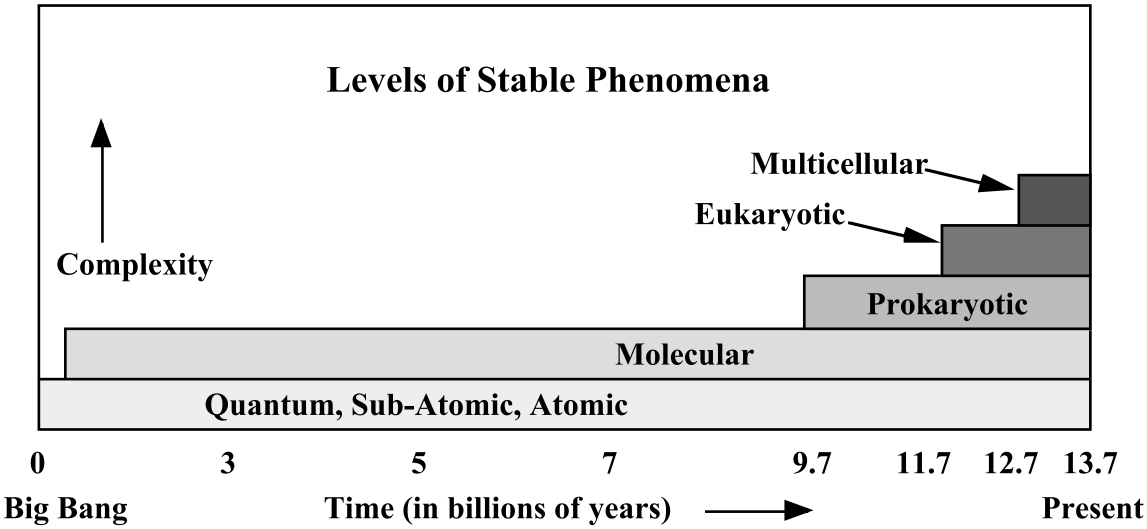
1) Scale in size - one millionth of human scale or 1 x $10^{-6}$ meter
2) Self Organization - organization of complex macro-molecules into a self-reproducing unit, the cell
3) Emergent Properties & Processes - the origin of life—Archaebacteria & Eubacteria; natural selection; speciation; self-reproduction by binary fission; anaerobic and aerobic respiration; photosynthesis

**The Eukaryotic (origin ~ 2000 million years ago)**

1) Scale in size - 1 x 10 $^{-5}$ to 1 x 10 $^{-4}$ meter or ten to a hundred times larger than the prokaryotic
2) Self Organization - endosymbiotic mutualism of primitive eukaryotes and prokaryotic bacteria to form true eukaryotic cells
3) Emergent Properties & Processes - endosymbiotic mutualism; origin of Kingdom Protista; evolution of sexual reproduction (origin ~ 1100 million years ago)

**The Multicellular (origin ~1000 to 600 million years ago)**

1) Scale in size - one thousandth of human scale to human scale or 1 x 10 $^{-3}$ to 1 meter
2) Self Organization - multicellular organization by cell types into tissues and organs, to whole organisms; reproductive groups (demes); social organization (societies)
3) Emergent Properties & Processes - cell specialization; emergence of large life forms; origin of Kingdoms Fungi, Plantae, and Animalia; social behavior; language



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## The Evolution of the Universe—The Short Version

“Yes, the universe had a beginning [approximately 14 billion years ago]. Yes, the universe continues to evolve. And yes, every one of our body’s atoms is traceable to the Big Bang and to the thermonuclear furnace within high-mass stars. We are not simply *in* the universe; we are part of it. We are born from it.”—Neil DeGrasse Tyson, 1998a

Neil DeGrasse Tyson, an astrophysicist, is the director of New York City’s Hayden Planetarium.

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## Astronomical Distances—How big is "Big"?

The diameter of the Earth is 7926.4 miles or 12,756.3 kilometers (km). The average separation of the Earth from the Sun is 149.6 million km. This is 11728 times the Earth's diameter. This defines an Astronomical Unit (AU) which is the preferred unit of measure for distances within our solar system. Converted to miles the Earth is 93 million miles from the Sun. It takes light 8.3 minutes to travel from the Sun to the Earth.

A light year or the distance light travels in a year is used to measure distance outside of our solar system. It is 9.45 trillion kilometers or 5.88 trillion miles. To put a light year in perspective, an Astronomical Unit is 0.0000158 of a light year.

The speed of light (c) is one of the fundamental constants in nature. The speed of light in a vacuum is exactly c = 299,792,458 m/s (meters per second). This is 299,792 kilometers per second or 186,300 miles per second (the conversion factor is km x 0.62143 = miles). The speed of light is normally rounded to 300,000 km/sec or 186,000 miles/sec.

When people refer to the speed of light, they refer to the definition above—the speed of light in a vacuum. The speed of light depends on the material that the light moves through—for example: light moves slower in water, glass and through the atmosphere than in a vacuum. The ratio whereby light is slowed down is called the refractive index of that medium. In general for astronomical distances, the difference in the speed of light in other mediums is ignored because of the emptiness of space.

## Some Representative Distances

The Solar System is about 80 Astronomical Units in diameter or 7.44 billion miles.

The nearest star to Earth (other than the Sun) is Proxima Centauri about 4.3 light years or 25.3 trillion miles away.

Our galaxy (the Milky Way) is about 100,000 light years in diameter (588 thousand trillion miles).

The nearest galaxy to the Earth is the Large Magellanic Cloud about 50 kilo parsecs away. A parsec is 3.26 light years making the Large Magellanic Cloud 1,540,000,000,000,000,000 kilometers away (which is about 1 million, trillion miles).

The visible universe is approximately 93 billion light years in diameter, which is 9.3 x $10^{29}$ kilometers across or 9.3 x $10^{32}$ miles.

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**"The universe is not just stranger than we imagine, it is stranger than we can imagine."**

(paraphrase of J.B.S. Haldane from *Possible Worlds*, 1927)

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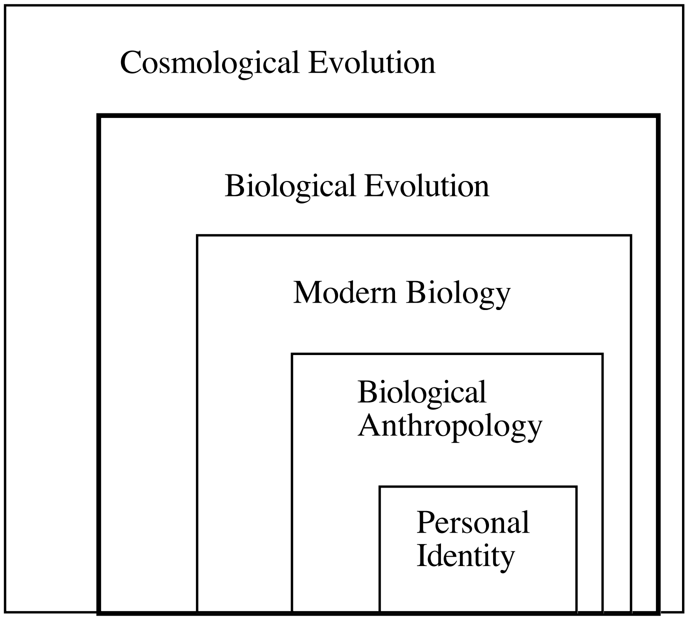
## Unit Two: Biological Evolution

**Increasingly Inclusive Concepts in Science**



Biological evolution is more inclusive than modern biology because it includes a large part of modern geology. The history of life on Earth and the geological history of the Earth are intimately tied together.

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"There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved."

Charles Darwin from the last line of

*On the Origin of Species by Means of Natural Selection, or the Preservation of Favored Races in the Struggle for Life.*
(1859)

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"Never in the field of scientific endeavor can so great a theory [evolution by natural selection] have been misunderstood by so many with so little reason."—Ridley, 1995

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## Darwin's Five Theories

(after Mayr, 1982, 505)

1) **Evolution as Historical Fact**—The mutability of species or evolution as such

2) **Common Descent**—all organisms have descended from common ancestors by a continuous process of branching speciation

3) **Gradualism**—the mode of evolutionary change is gradual—gradual changes within a population as opposed to sudden changes between generations

4) **Speciation**—the process of multiplication of species

5) **Natural Selection**—the mechanism of evolutionary change

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• **Point:** Evolutionary theory is not just one scientific theory and involves much more than most people think.

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## Questions

• How did the species of plants and animals we see today originate?

• Have each of these life-forms remained the same since they originated?

• Has the number and types of species remained the same through time?

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## Evolution as Historical Fact

"For biologists of today, evolution is no longer a hypothesis but simply a fact, documented by the changes in the gene pools of species from generation to generation and by the changes in the fossil biota in accurately dated geological strata. Current resistance is limited entirely to opponents with religious commitments."—Mayr, 1982

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## Evolution by Common Descent

### The Weak Version

“all organisms have descended from common ancestors by a continuous process of branching speciation.”—Mayr, 1982

### The Strong Version

The strong version of Darwin’s theory views life at the molecular, genetic level from the perspective of non-linear thermodynamic systems. It is from this perspective that the conclusion is derived that life is “a single, ongoing, genetically controlled chemical chain reaction.”

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• **Note:** “branching” speciation is allopatric speciation, i.e. parent species “branch” off geographically and give rise to daughter species where both species survive at least for a time.

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## Gradualism

The Tempo and Mode of Evolution: Gradual or Punctuated?

The rate of evolutionary change in populations of organisms has varied greatly over geological time. This is the **tempo** of evolutionary change and is related to the multiplication of species. It now appears to be true that this tempo consists of long periods of little change called stasis that are punctuated by rapid (rapid in terms of geological time) periods of evolution. This is punctuated equilibrium.

But the **mode** of evolutionary change by slight variations caused by small mutations is always a gradual process: “It is the slow, cumulative, one-step-at-a-time, non-random survival of random variants.” (Dawkins, 1996). This is expressed in the metaphor of Mount Improbable.

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## Speciation

### Allopatric or Phylogenetic or both?

“A new species develops if a population which has become geographically isolated from its parental species acquires during this period of isolation characters which promote or guarantee reproductive isolation when the external barriers break down.”—Mayr, 1982

**Point:**

- **Allopatric speciation is speciation that takes place in geographic space.**
- **Phylogenetic speciation is speciation that takes place through time.**
- **Both, however, must occur to produce a new species.**

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## A Note on Terminology

**Cladogenesis**: Evolution in which a daughter species splits off from a population of the older species, after which both the old and the young species coexist together. Notice that this allows a descendant to coexist with its ancestor. Cladogenesis is the type of evolutionary change that occurs in allopatric speciation.

**Anagenesis**: Evolution in which an older species, as a whole, changes into a new descendent species, such that the ancestor is transformed into the descendant. Anagenesis is the type of evolutionary change that occurs in phylogenetic speciation.

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## Population Thinking

Ernst Mayr has shown that, in order to understand evolution by natural selection, we must look to the nature of populations and not of individuals.

- **Individual organisms do not evolve; only populations of interbreeding organisms evolve.**

- **Only populations have continuity through time; individual organisms are temporary.**

It was also Ernst Mayr who set population thinking in opposition to Platonic essentialism (see essays on the Medieval worldview) to help us understand the difference between evolutionary thinking and the antiquated notion of the fixity of species. Essentialism held that each species had a fixed spiritual essence or ideal form and that any variation was, therefore, a corrupt deviation from this pure form.

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## Natural Fecundity

“There is no exception to the rule that every organic being naturally increases at so high a rate, that if not destroyed, the Earth would soon be covered by the progeny of a single pair.”

—Charles Darwin from *On the Origin of Species*, page 64.

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## Natural Selection

- Over Production (caused by Natural Fecundity)

coupled to

- Variation that can be Inherited

leads to

- Differential Reproductive Success

which leads to

- Evolutionary Adaptation to Changing Local Environments

(after Gould, 1977)

**Points:**

- Natural selection is a dynamic process and not a person or a thing.

- It is reasonable to equate natural selection to circumstances.

- Natural selection only operates in the present, i.e. it is only the circumstances of the present that count in the process.

- Present **circumstances** (natural selection) operating on individuals results in **changing** (evolving) populations.

In other words, evolution by natural selection is a **nature algorithm**.

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## Defining a Natural Algorithm

Using Daniel Dennett's definition from his book *Darwin's Dangerous Idea* (1995, 50-51) an algorithm has:

1) **substrate neutrality**: The power of the process is due to its *logical* structure, not the properties of the materials involved in its particular occurrence.

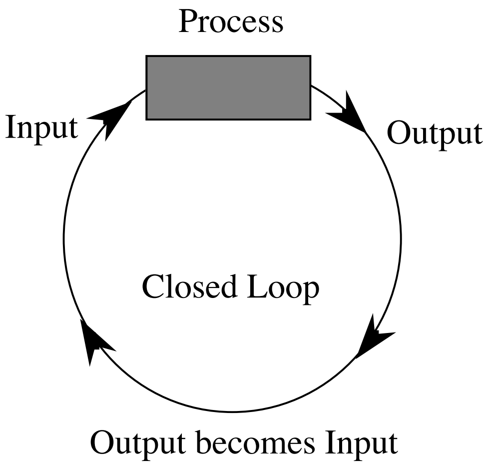
2) **underlying mindlessness**: Although the overall organization of the process may yield brilliant results, each constituent step, as well as the transition between steps, is utterly simple.

3) **guaranteed results**: Whatever it is that an algorithm does, it always does it. If it occurs without misstep, an algorithm is a foolproof recipe.

This does not mean that an algorithm must always produce the same result. Algorithms of natural processes always operate on a unique set of initial conditions, that, in turn, produce historically contingent outcomes. What evolutionary algorithms are a foolproof recipe for is cumulative change, where each outcome of the algorithmic process operating on an historical system is different from the last. What is guaranteed is change itself.

What Dennett doesn't clarify until later in his book is that, as it concerns evolution in natural systems, we are talking about *natural* algorithms—algorithmic processes in nature that have the above characteristics but do not have an end directed goal. They exist and operate but they are not algorithms for producing particular outcomes. They have no teleological purpose, no "final cause". This is Aristotle's fourth division of causality, and it is final not in the temporal sense of coming last, but in the Latin meaning of ultimate purpose. Natural algorithms are distinct from *constructed* algorithms—algorithms that have been created by humans to produce particular outcomes as in mathematics and computers.

Cause and Effect in a Closed System



The natural algorithm of evolution by natural selection is a process that operates on the closed historical system of genetics and reproduction of life on Earth. Using the figure above the “process” of evolution works on the gene pool of every population of organisms and results in the “output” of a unique gene pool every generation in the population. This then is the only gene pool (the input) available to produce the next generation. The only way to stop this process would be to insure that there was absolutely no genetic change, no random mutations in DNA, no differential reproduction, nothing throughout the entire history of the population. Every generation’s gene pool would have to be genetically identical to the last one, and given the nature of genetics and reproduction, this is clearly impossible.

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## Adaptations

Evolution by natural selection does not lead to optimal adaptations. It produces only historically constrained answers to past environmental challenges. What worked in the past was cobbled together from what was genetically available then and has no guarantee of working in the future. Evolutionary adaptations are always a gamble that future conditions will be similar to the past. If the environment changes a highly specialized adaptation may suddenly become useless if not a liability.

**• In reality the only "adaptation" natural selection "selects" is reproductive success.**

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• **Point:** The point is that natural selection allows only what "works" to continue into the next generation, but the measure of every adaptation is in how it works to enhance reproductive success. Reproductive success is, therefore, the measure of every adaptation.

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## Questions

- **What are the implications of our growing scientific knowledge of the world?**

- **What if the great thinkers of the past, such as Plato or Augustine, knew what we now know about the natural world?**

- **Could our ability to understand certain ideas depend on our beliefs and values?**

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• **Point:** This last question ties directly back to the presentation of "Worldviews, Values, and Decision-making". The point to be made is that people may be unable to understand evolution by natural selection if they have been indoctrinated in an epistemology that is antithetical to the epistemology of science. The entire issue reduces down to what an individual believes is acceptable evidence. If they accept the word of authority as acceptable evidence, they may be unable to grasp scientific understanding.

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## Unit Three: Life as a Chemical Function

**Introduction:** We gained a fundamentally new understanding of nature when scientific research was able to shift scale in size from the macroscopic, or human scale, to the nanometer scale of molecules. This is one of the strengths of the reductionist method in science. Biology today is characterized by this reductionist program; we live in the age of molecular biology.

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### The Chemical Dimension of Life—Biochemistry

**• atoms —> to molecules —> to macromolecules**

There are four main groups of biologically important macromolecules:

**(1) Proteins** both structural such as keratin, and regulatory such as enzymes

**(2) Nucleic Acids** such as DNA and RNA

**(3) Carbohydrates** such as glucose, a simple sugar

**(4) Lipids** such as fatty acids that form membranes

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### Four Levels of Protein Structure

- The first or ***Primary Level*** is simply the order of amino acids in a polypeptide chain.

- The ***Secondary Level*** is the first folding of the polypeptide chain into either an Alpha Helix or Beta Pleated Sheet.

- The third or ***Tertiary Level*** is the second folding of the polypeptide chain into a Globular Protein which may contain both helix and pleated sheet structures.

- The fourth or ***Quaternary Level*** consists of more than one globular protein that combine together to form the finished protein.

- **Hemoglobin** is an example of Quaternary structure.

- In all cases, it is the ***final shape*** of the protein that determines its chemical activity.

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## Nucleic Acids and Protein Synthesis

**• Transcription**

DNA (genes) —> to mRNA —> to ribosomes

**• Translation**

amino acids —> to tRNA —> to ribosomes —> makes proteins

**• Genes code only for proteins and RNAs**

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## The Genealogical Dimension of Life—Genetics the information dimension

### Terms and Definitions to Know

- genes —> genetic information
- genome —> genetic makeup of the individual
- gene pool —> genetic makeup of a population
- biodiversity —> genetic sum of all of life on earth
- genotype —> • phenotype

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"The gene pool of a population is a record of reproductive success and failure in that population, and at conception an organism gets a sample of this record. The sample is its instructions for producing the machinery by which it adapts to its environment. All other useful information, such as that learned and stored in the brain, depends on the initial genetic information. New information can be exploited [only] because organs for the gathering, storage, and use of information are specified in the genes. Such organs are no less biological than those for the gathering, storage, and use of food. Both kinds of organs are there because they have been useful in previous generations for transmitting genes to later generations."

George C. Williams from his essay *A Sociobiological Expansion of Evolution and Ethics* in Paradis & Williams (1989)

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## Essay—Nature, Nurture, or Neither

### The Failure of both Cultural and Genetic Determinism

There has been a long running battle between the social sciences and the natural sciences over the causal source of human behavior (Degler, 1991). The struggle is between the view that our behavior is culturally determined versus the view that our behavior is genetically determined. The debate has traditionally been known as nature versus nurture. It establishes a dichotomy between the influences of “nature” which today we recognize as our genetic makeup, our genome, and “nurture” which is shorthand for the environmental, cultural determinants of behavior.

Simple logic should have resolved this debate long ago, if only the parties to the debate had recognized that there is no evidence that precludes the obvious combination of genetic and environmental influences in determining our behavior. The western mind-set of thinking in opposites, however, has a long tradition beginning with the early Greek philosopher Anaximander. It was Anaximander who first proposed that nature was composed of opposites: hot and cold, wet and dry, light and heavy, life and death (Burke 1985, 16). We continue this tradition by thinking that behavior must be determined by one of two opposites, nature or nurture.

This debate, however, sets up a false dichotomy. In a true dichotomy a position is set against its only possible alternative. In a false dichotomy these two alternatives do not exhaust all the possible explanations of the phenomenon. The key to understanding the false dichotomy of "nature versus nurture" is that neither nature nor nurture *alone* determines our behavior. There is an obvious third alternative.

Today, although the debate still goes on, there is a growing consensus that our behavior is determined by a dynamic interaction between our genes and the environment. In biology this product of the interaction between a genome and its environment is called the **phenotype**. Our behavior should be seen as a purely phenotypic response of our genome to the external world.

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## Genetics and Reproduction—Terms and Definitions to Know

- genetic mutations
- allele
- variation in genes
- variation in alleles
- dominant alleles
- recessive alleles
- heterozygote
- homozygote
- gene expression
- single gene traits
- polygenic traits
- pleiotropy
- somatic cells
- germ cells
- mitosis
- meiosis

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### Biochemical Evidence for the Unity of Life

- DNA is the universal genetic material.
- The process of protein synthesis is universal.
- The genetic code for specifying amino acids is universal for all life-forms.
- Metabolic pathways for producing energy such as glycolysis and the cycling of ATP and ADP are universal for all life-forms.

It was the great 18th century French chemist, Antoine Lavoisier (1743-1794), who first asserted that life is a chemical function. Modern molecular biology has reinforced that all the phenomena we associate with life are the product of the chemistry of life. It is not, therefore, misleading to say that life is a single, ongoing, genetically controlled chemical chain reaction. That this incredibly complex chemistry is common to all life-forms is compelling evidence for the unity of life based on common descent (Moore, 1993).

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## Unit Four: The Modern Synthesis

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### The Same but not the Same

Who was the first geneticist?

Darwin **or** Mendel

Why was Darwin unable to figure out the mechanism of inheritance?

Why was Mendel able to?

Reduction or Holism / Numerate or Innumerate

Darwin **and** Mendel

The “Modern Synthesis” of Evolution by Natural Selection and Genetics

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### Essay—Darwin and Mendel: Who was the first geneticist?

Gregor Mendel is acknowledged as the first geneticist, and no one would argued that he wasn’t. But there is a growing awareness that Darwin’s influence should be recognized in the history of genetics. Darwin’s theory of evolution by natural selection creates the theoretical need for understanding the mechanism of inheritance. But Darwin was ultimately a synthetic rather than a reductionist thinker. His view was of the whole. As Colin Tudge offers, “Darwin, I believe, was simply the wrong kind of thinker to arrive at the correct mechanism of heredity. He conceived his grand over-view of evolution by looking at thousands of different instances, in thousands of different species: beetles, finches, barnacles, orchids, human beings; in other words, through the eyes of a tremendously accomplished naturalist. Nothing short of such a grand sweep could suggest a convincing mechanism that could be seen to apply to all of them."—Tudge, 1993, 6

"Darwin produced the theory that has transformed biology, and indeed has changed the course of modern philosophy more profoundly than that of any other thinker of the past three centuries. Yet the mechanism he proposed [natural selection] cannot work unless the process of heredity operates in a particular way: a way that can produce variation from generation to generation even while respecting the general condition that 'like begets like' [i.e. the same but not the same]. But what that mechanism might be Darwin failed absolutely to perceive.

Here we come to yet another irony, in fact to several more. First, the mechanism of inheritance that Darwin sought and needed was worked out and published during his own lifetime [in 1866]—indeed, just a few years after *On the Origin* appeared—by a scientist-monk [Mendel] in what was then called Moravia [now the Czech Republic]. Second, however, this crucial insight was overlooked by the scientific community at large, and was in fact forgotten until rediscovered at the beginning of the twentieth century. Third, when the vital mechanism of inheritance was finally rediscovered, it was not at first recognized as the key to evolution by natural selection."—Tudge, 1993, 10

Darwin's holistic viewpoint, as well as his being innumerate, prevented him from being able to determine the mechanisms of inheritance. Mendel on the other hand was trained as a physics teacher in a time when the reductionist methodology was being rigorously promoted, and Mendel was numerate. The question then "Who was the first geneticist?" reveals the tension between the reductionist and the holistic methods in science. But the central point must not be lost—both methods are necessary for science to progress toward its goal of understanding nature. Mendel completed what Darwin had begun, a true understanding of inheritance.

The story is not complete, however, until the modern synthesis of evolution by natural selection and genetics is achieved in the twentieth century. It was not until the 1940's that Julian Huxley (T.H. Huxley's grandson) would coin the term "the Modern Synthesis" to describe the grand unification of evolutionary theory with classical genetics that had finally taken place. In America Ernst Mayr, Theodosius Dobzhansky, George G. Simpson, and G. Ledyard Stebbins were the major figures in creating this synthesis. With the achievement of the modern synthesis Darwin's theory of evolution by natural selection once again demonstrated its consilient power in bringing all of biology under one theoretical framework.

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• **Point:** It should now be clear that only when both methods, reductionism and holism, are combined, as in the modern synthesis, do we come to fully understand the natural world.

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## Part Three: The Integration of Biological Knowledge

### Introduction:

"Science analyzes experience, yes, but the analysis does not yet make a picture of the world. The analysis provides only the materials for the picture. The purpose of science, and of all rational thought, is to make a more ample and more coherent picture of the world, in which each experience holds together better and is more of a piece. This is a task of synthesis, not of analysis."—Bronowski, 1977, 253

Because life on Earth is an effectively closed historical system, we must understand that biology is an historical science. One result of this is that a chronological narrative of the history of life provides for the integration of all biological knowledge.

The late Preston Cloud, a biogeologist, was one of the first scientists to fully understand this. His 1978, book *Cosmos, Earth, and Man: A Shot History of the Universe*, is one of the first and finest presentations of "a more ample and more coherent picture of the world".

The second half of this course follows in Preston Cloud's footsteps in presenting the story of the Earth and life through time.

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## Unit One: Geologic Time

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**"I am convinced that we can only understand the present by understanding the past."**

—Peter D. Junger

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### On the Origin of our Solar System and the Age of the Earth

How did the Sun and the planets form, and what lines of scientific evidence are used to establish their age including the Earth's?

1. the Sun's luminosity
2. the radiometric age of Moon rocks
3. the radiometric age of meteorites

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## Geologic Time and the Limits of Human Perception

Our perception of time is limited. The issue is again scale, but now of time rather than size.

**Points:**

1. Because of our limited life experience we are locked in “human time”.

2. “The Last Six Minutes” Phenomenon—we equate the present to the past, as if the world has always been as it is now.

3. Human Time opposed to Geologic Time—human time is at the wrong scale for understanding the history of life.

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## Native Amnesia

“We are born in ignorance of the events that took place before our birth, and through the study of history we seek to overcome this native amnesia. We can hear about the most recent events by asking our parents and grandparents, who remember them. History from the times before living memory is written in documents, both the original writings of people long gone and the books written by scholars of history. Through the words represented by symbols on paper we are carried back through 5,000 years, back to the earliest writings, learning the thoughts and deeds of the people who lived before us.

Yet 5,000 years takes us back only a *millionth* part of the lifetime of the Earth. Back beyond the invention of writing stretches an almost endless abyss of time, during which the events took place which determined the kind of creatures we are and the kind of world we live in. It is only in the last couple of centuries that we have learned to decipher the events of this forgotten eternity and to write down its history.”—Alvarez 1997, 19

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## Geologic Dating

### How are dates arrived at for the geologic time scale?

1. Steno’s Law—also known as the Law of Superposition—states that, if undisturbed, lower sedimentary layers are always older than upper layers.

2. Using Steno’s law layers of sedimentary rocks that contain different fossils give relative dates for those fossils.

3. Radiometric dating using radioactive isotopes gives absolute dates.

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# The Geologic Time Scale

The units of time, starting with the longest, are Eons, Eras, Periods, and Epochs.

All dates are in millions of years ago (m.y.a.).

## Hadean Eon — 4600 to 4000 m.y.a.

| | |
|---|---|
| major events: | formation of the earth |
| | meteorite impact age |

## Archean Eon — 4000 to 2500 m.y.a.

| | |
|---|---|
| major events: | origin of life |
| | evolution of photosynthesis |
| | evolution of aerobic respiration |

## Proterozoic Eon — 2500 to 542 m.y.a.

| | |
|---|---|
| major events: | evolution of complex eukaryotes |
| | evolution of sexual reproduction |
| | evolution of multicellular life |

Collectively, the first three eons are known as the **Precambrian**.

## Phanerozoic Eon — 542 m.y.a. to the present

### Eras of the Phanerozoic Eon

Paleozoic Era — 542 to 251
Mesozoic Era — 251 to 65
Cenozoic Era — 65 to present

### Periods of the Paleozoic Era

Cambrian — 542 to 488
Ordovician — 488 to 444
Silurian — 444 to 416
Devonian — 416 to 360
Carboniferous — 360 to 299
Permian — 299 to 251

### Periods of the Mesozoic Era

Triassic — 251 to 200
Jurassic — 200 to 145
Cretaceous — 145 to 65

### Periods & Epochs of the Cenozoic Era

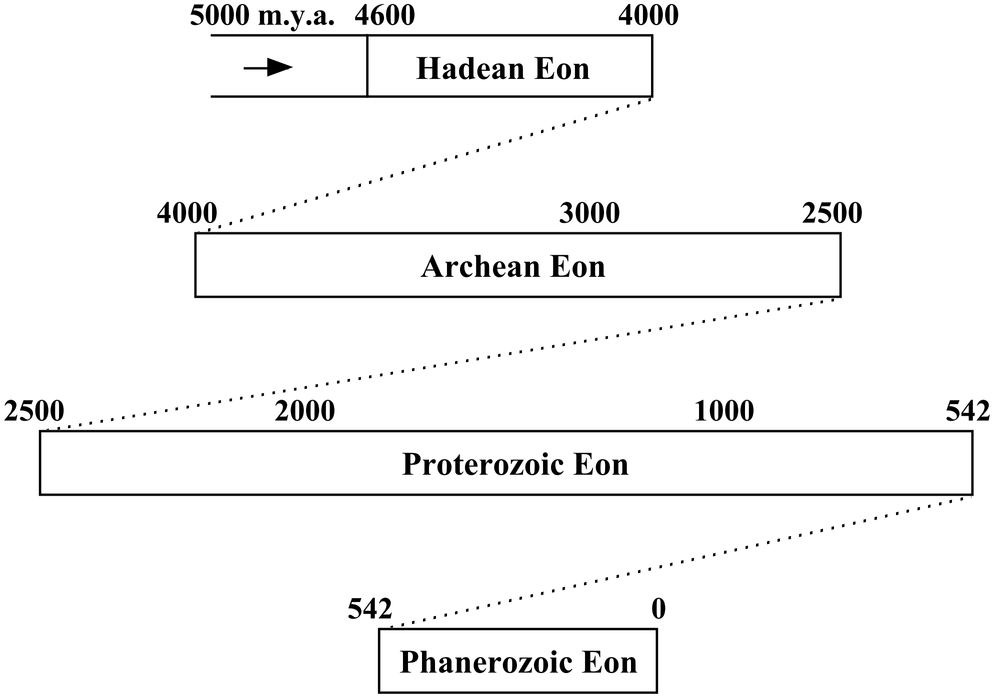
#### Paleogene Period

Paleocene — 65 to 56
Eocene — 56 to 34
Oligocene — 34 to 23

#### Neogene Period

Miocene — 23 to 5
Pliocene — 5 to 1.8
Pleistocene — 1.8 to 0.01
Holocene — 0.01 to the present

## Geologic Timeline



### Major Features of Life on Earth

In studying the history of life on Earth it is important to note the major features of that history. The issue is the degree of coarse or fine graining that we use; we want to be able to see the forest as well as the trees.

1. Microbial (single cell) life forms are the dominant form of life on Earth both from the view of longevity and in terms of sheer biomass—life's dominant form is microbial.

2. The vast majority of life for almost all of the history of life on Earth lived and does live in the sea—life's predominant habitat is the sea.

3. Life has evolved from the small to the large.

4. Life has evolved from the simple to the complex.

5. There is a necessary sequence to the history of life's evolution, even while that history was not pre-determined.

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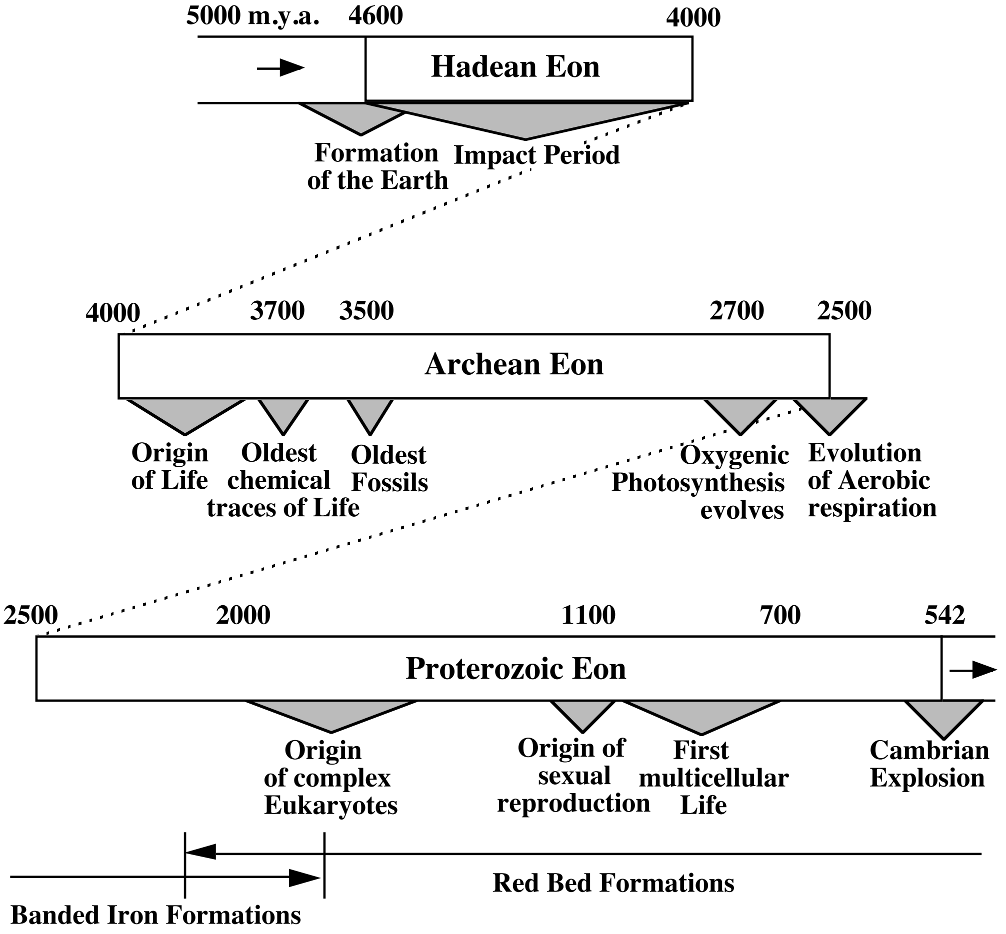
## The Precambrian



## Major Events in the Precambrian

1. the formation of the Solar System
2. the formation of the Earth
3. end of meteorite impact period
4. the origin of life (anaerobic prokaryotes)
5. the evolution of photosynthesis (photoautotrophic prokaryotes)
6. the evolution of aerobic respiration (heterotrophic and autotrophic, aerobic prokaryotes)
7. start of oxygen build-up in Earth's atmosphere
8. the evolution of complex eukaryotic cells (heterotrophic and photoautotrophic eukaryotic protists)
9. the evolution of sexual reproduction
10. the evolution of multicellular life (fungi, plants, and animals)

## Unit Two: The Origin of Life

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### The Origin of Life on Earth

- When did life originate?
- Where was it most likely to have originated?
- What is the current working hypothesis as to how it originated?

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### The Window of Opportunity

between 4200 m.y.a. at the end of the impact frustration of the origin of life
and 3500 m.y.a. first fossil evidence of life

### Estimates

deep sea vent abiogenesis 4200 to 4000 m.y.a.
surface abiogenesis 4000 to 3700 m.y.a.
(abiogenesis—the origin of life by chemical evolution)

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### Chemical Evolution

"Given the physical-chemical conditions that prevailed on our planet 4000 m.y.a., a protometabolism leading to RNA-like molecules was bound to arise along well-defined, reproducible chemical lines."—Christian de Duve from his book *Vital Dust* (1995)

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### Abiotic Molecular Building Blocks

### Amino acids, Stanley Miller and the 1953 experiment

"Life began when some compound or class of compounds developed the ability to copy itself in such a way that it occasionally made heritable 'mistakes'. These mistakes sometimes produced generations of molecules that could replicate more efficiently than their predecessors."
—Stanley Miller in Horgan, 1991

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## The “RNA World” Hypothesis for the Origin of Life

How did protein synthesis evolve if it takes protein enzymes to mediate the process of transcription and translation? The answer came with the discovery that RNAs can be both an information molecule, a gene, and an enzyme—a **ribozyme**. Thomas Cech and Sidney Altman won the Nobel Prize in 1989, for discovering the ribozyme function of RNA.

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One possible **“RNA World”** scenario, showing the transition
from the prebiotic RNA world to the biotic DNA world.

1. Creation of prebiotic soup, including nucleotides, from Earth’s primitive atmosphere

2. Production of short RNA molecules with random sequences

3. Selective replication of self-duplication catalytic RNA segments

4. Synthesis of specific peptides, catalyzed by RNA

5. Increasing role of peptides in RNA replication; coevolution of RNA and proteins

6. Primitive translation system develops, with RNA genome and RNA-protein ribosomes

7. Genomic RNA begins to be copied into DNA

8. DNA genome, translated on RNA-protein ribosomes

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- **Note:** Recent discoveries have shown that RNA, and not protein enzymes, catalyses the formation of peptide chains in ribosomes. This discovery adds support to the “RNA World” hypothesis of the origin of life by showing that RNA acting as a ribozyme still plays a central role in the most basic of all cellular metabolic functions (Cech, 2000).

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# Unit Three: Photosynthesis & Aerobic Respiration

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## Life and the Exploitation of Energy

What has driven evolutionary change in the history of life? One answer is that life has evolved toward ever more complex ways of acquiring energy. This is by no means the only driving force behind evolution, environmental change is fundamentally important. But to understand life on Earth, we must understand something of the chemistry of life's energy.

## Terms and Definitions to Know

• Eubacteria • Archaebacteria

• Heterotrophs • Autotrophs

• Photoautotrophs • Chemoautotrophs

• Aerobic • Anaerobic

• Photosynthetic Bacteria • Stromatolites

• Oxygenic Photosynthesis • Anoxygenic Photosynthesis

• Cyanobacteria • Purple & Green Sulfur Bacteria

• **Note**: Eubacteria and Archaebacteria are now commonly refer to as Bacteria and Archaea. They are classified as Domains, a larger, more fundamental taxon than Kingdoms.

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## The Evolution of Photosynthesis

Photosynthesis exists in all the major taxonomic divisions of life. It occurs anywhere there's light energy, over a wide range of temperature, light and aeration conditions. Photoautotrophy occurs widely throughout the Eubacteria, and is an ancient trait. Fossil stromatolites in 3.5 billion year old rocks show that photoautotrophic prokaryotes evolved early in the history of life.

Photosynthesis is one of the most important biological processes on the planet. Besides producing almost all organic carbon on Earth, photosynthetic organisms completely transformed the planet to the way it is now. Early photosynthesis was anoxygenic (it did not produce $O_2$ gas). When oxygenic photosynthesis evolved, our atmosphere as we know it was created, including the ozone layer which allowed life to evolve on land.

## Anoxygenic Photosynthesis

$H_2S$, or $H_2$, or organic compounds are used as hydrogen donors, and $CO_2$ and organic compounds as carbon donors

Example organisms are purple and green sulfur bacteria.

Purple sulfur bacteria use Photosystem II to make organic molecules.

Green sulfur bacteria use the TCA cycle (Photosystem I) to make organic molecules.

## Oxygenic Photosynthesis

$H_2O$ is used as the hydrogen donor, and $CO_2$ as carbon donor.

Example organisms are cyanobacteria, algae, and plants.

Oxygenic photosynthesis uses both Photosystem I & II, known as the Calvin-Benson cycle, to make organic molecules.

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## Purple and Green Sulfur Bacteria

Because of their unusual mechanisms for harvesting and using the energy of light, the purple and green sulfur bacteria are important in understanding the evolution and mechanisms of both photosynthesis and cellular energy metabolism. The ability to carry out photosynthesis in the absence of oxygen is particularly important to evolutionary studies because the early atmosphere of Earth had little oxygen. This is why scientists have suggested that the purple and green-sulfur bacteria were the first photosynthetic organisms. This has since been corroborated by genetic studies (Xiong, et al, 2000).

Green sulfur bacteria are widely distributed in aquatic environments where light reaches anoxic (low-oxygen) layers of water containing reduced sulfur compounds. When researchers analyzed the microbe's single circular chromosome, they identified numerous genes that play novel roles in photosynthesis or other processes that make use of the energy of light.

Green sulfur bacteria are also unique because their mechanism for capturing carbon dioxide differs from that of cyanobacteria and plants. The green sulfur bacteria use an unusual chemical cycle—called the reductive tricarboxylic acid (TCA) cycle—that differs from the Calvin Cycle that is used by cyanobacteria and plants. The TCA cycle uses hydrogen from hydrogen gas ($H_2$) or hydrogen sulfide ($H_2S$) to fix carbon dioxide; in contrast, the Calvin Cycle uses water ($H_2O$).

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## Cyanobacteria & Oxygenic Photosynthesis

Carbon Hydrogen Oxygen

$CO_2$ $H_20$ $C_6H_{12}O_6$ $O_2$
carbon dioxide and water plus sunlight produces carbohydrates and oxygen gas

in the formula ratio of

six $CO_2$ + six $H_2O$ —> plus energy —> one $C_6H_{12}O_6$ + **six** $\mathbf{O}_2$

The problem with oxygenic photosynthesis is that

**oxygen gas is dangerously corrosive**.

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## Essay—The Oxygen Holocaust

"The oxygen holocaust was a worldwide pollution crisis that occurred about 2500 m.y.a.. Before this time there was almost no oxygen in the Earth's atmosphere. The Earth's original biosphere was as different from ours as that of an alien planet. But purple and green photosynthetic microbes, frantic for hydrogen, discovered the ultimate resource, water, and its use led to the ultimate toxic waste, oxygen. Our precious oxygen was originally a gaseous poison dumped into the environment. The appearance of oxygenic photosynthesis and the resulting oxygen-rich environment tested the ingenuity of microbes, especially those producing oxygen and those non-mobile micro-organisms unable to escape the newly abundant and reactive gas by means of motion. The microbes that stayed around responded by inventing various intracellular devices and scavengers to detoxify—and eventually exploit—the dangerous pollutant."—Margulis, 1986

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## The Great Oxygen Crisis 3000 to 2000 m.y.a.

**Point 1** — It now seems clear that life could not have originated in the presence of oxygen.

**Point 2** — Early life had to find a new source of energy as the early chemoautotrophs over-populated their ocean bottom world.

**Point 3** — Early life had to adapt to the surface waters of the ocean to utilize sunlight as an energy source.

**Point 4** — The first oxygenic photosynthetic bacteria had to neutralize the effects of the waste product of photosynthesis—oxygen.

**To neutralize the effects of oxygen**

**Plan A**: have something get rid of the oxygen while you adapt to it

Oxygen “sinks” and the Banded Iron Formations—oxygen in the sea 3500 to 1800 m.y.a.

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- **Note:** Iron dissolves readily in water in the absence of oxygen but turns to a solid precipitate and sinks if oxygen is present.

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**Plan B**: evolve chemical defenses against oxygen

The “Red Bed” Iron Formations—oxygen in the atmosphere 2100 m.y.a. to the present

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## Defenses against Oxidative Damage

A variety of molecular defenses in our cells prevent or repair molecular damage caused by free oxygen radicals.

**Antioxidants** (macromolecules that neutralize free radicals or otherwise limit their activity)

**Vitamin E and beta carotene**—react with free oxygen radicals preventing them from attacking cellular constituents; are fat soluble and so can protect membranes.

Uric acid and **Vitamin C**—react with free oxygen radicals in the cytoplasm.

**Repair Systems** (protein enzymes that degrade, repair or replace damaged molecules)

Proteinases—cleave oxidized proteins.

Peptidases—chop up products of protease activity; amino acids can then be recycled to make new proteins.

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**Point 5** — Meanwhile heterotrophic bacteria had two choices: retreat away from the growing oxygen environment or also evolve adaptations to neutralize oxygen.

**Point 6** — The product of photosynthesis (carbohydrates) represented a new source of energy for heterotrophs to exploit.

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## Oxygenic Photosynthesis

$6\ CO_2 + 6\ H_2O$ —> plus energy in —> $C_6H_{12}O_6 + 6\ O_2$

but the following is also chemically possible

$C_6H_{12}O_6 + 6\ O_2$ —> **gives up energy** —> $6\ CO_2 + 6\ H_2O$

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## The Evolution of Aerobic Respiration

Aerobic Respiration is the chemical "burning" of carbohydrates to obtain energy for living cells. "Burning" in this sense is chemical oxidation.

$C_6H_{12}O_6 + 6\ O_2$ —> **gives up energy** —> $6\ CO_2 + 6\ H_2O$

carbohydrates plus oxygen "burns" and forms carbon dioxide and water

Aerobic respiration is the opposite of photosynthesis, but requires oxygen gas in the water or air in order to exist. It could not evolve, therefore, until oxygen had first built up in the oceans. Aerobic respiration evolved in both autotrophic and heterotrophic bacteria.

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## Essay—Aerobic Respiration and Mitochondria

"Aerobic respiration is on the order of 18 times more efficient in producing energy than anaerobic respiration.

Because of mitochondria, all earthly beings made of nucleated cells—which, of course includes us and all organisms except bacteria—have remarkably similar metabolisms. Discounting the photosynthetic metabolism monopolized by plants and algae (which is virtually identical to that of cyanobacteria), in all its fundamental details eukaryote metabolism is the same.

Bacteria, by contrast, exhibit a far wider range of metabolic variation than eukaryotes. They indulge in bizarre fermentations, produce methane gas, "eat" nitrogen gas right out of the air, derive energy from globules of sulfur, precipitate iron and manganese while breathing, combust hydrogen using oxygen to make water, grow in boiling water and in salt brine, store energy by use of the purple pigment rhodopsin, and so forth.

As a group bacteria obtain their food and energy by ingenious methods, using every sort of plant fiber and animal waste as a starting material. (If they did not, we would be living in a mounting heap of garbage. Bacteria are the ultimate recyclers.) We, however, use just one of their many metabolic designs for energy production, namely that of aerobic respiration, the specialty of mitochondria."—Margulis, 1986

• Note:  Mitochondria are the decedents of free-living, aerobic, heterotrophic bacteria closely related to existing alpha-proteobacteria. Mitochondria are genetically most similar to the alpha-proteobacteria *Rickettsia prowazekii*. Because of the similarities of their genomes, *Rickettsias* may be the closest living relatives to the ancestors of mitochondria.

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## Summary of the Steps in the Evolution of Trophic Strategies

**• Anaerobic Heterotrophs**

—the first life-forms had only the prebiotic soup to eat

**• Chemoautotrophs**

—the first autotrophs may have evolved at hydrothermal vents on the ocean floor and may have used hydrogen sulfide as their source of hydrogen giving off sulfur as waste

**• Anoxygenic Photosynthesis**

—the first photoautotrophs were anaerobic using hydrogen sulfide as their source of hydrogen and, therefore, did not produce oxygen as a waste

**• Oxygenic Photosynthesis**

—the second type of photoautotrophs used water as their source of hydrogen producing oxygen as a waste and eventually made the transition to aerobic respiration as oxygen levels increased

**• Aerobic Heterotrophs**

—heterotrophs also made the transition to aerobic respiration
as oxygen levels increased

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## Unit Four: Endosymbiosis & Eukaryotic Cells

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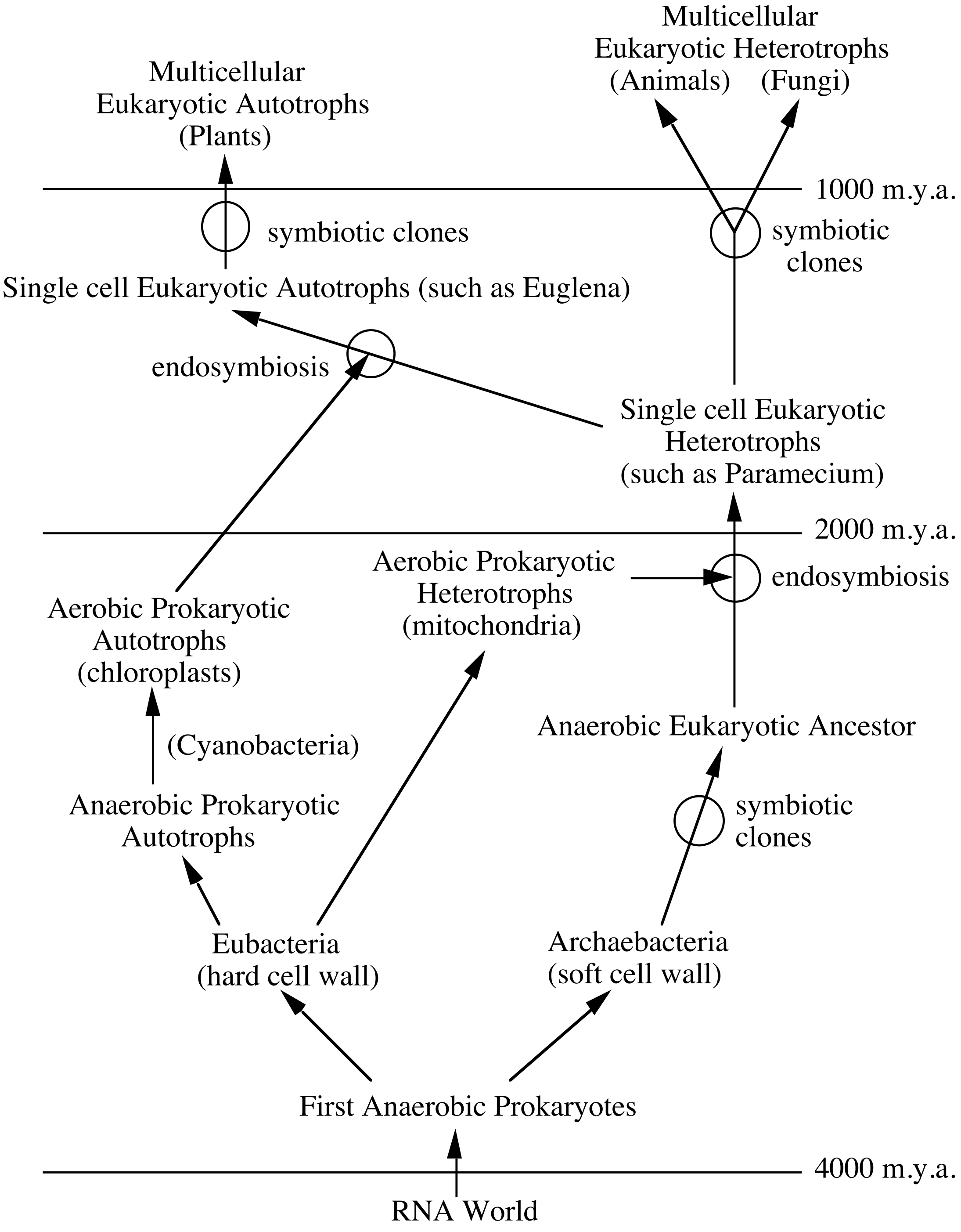
### Endosymbiosis and the Evolution of Eukaryotic Cells



## Unit Five: Sexual Reproduction & Multicellularity

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### Sex and the Evolution of Death

### Why Sex?

For slowly reproducing eukaryotic protists (compared to prokaryotes), sexual reproduction by the alternation of haploid and diploid phases has the advantage of rapid genetic mixing of existing genetic variation (Barton & Charlesworth, 1998).

### Why Death?

There are two issues concerning death:

1. Death and Uniqueness

In asexual reproduction, such as binary fission in prokaryotes, “offspring” are genetic clones of “parents”. It is therefore impossible to tell which is “parent” and which is “offspring”. Because of this, prokaryotic life is essentially immortal. As Lewis Thomas puts it in his essay *Death in the Open*:

> “There are some creatures that do not seem to die at all; they simply vanish totally into their own progeny. Single cells do this. The cell becomes two, then four, and so on, and after a while the last trace is gone. It cannot be seen as death; barring mutation, the descendants are simply the first cell, living all over again.”—Thomas, 1974

In sexual reproduction, however, because of the nature of cellular division by meiosis, offspring are always genetically different from their parents. For every sexually reproducing organism, each individual is genetically unique at the level of alleles. This genetic uniqueness of individual organisms, along with the division between body cells and reproductive cells in multicellular organisms, is what has given rise to our concept of death.

2. Why don’t individuals live forever? Why do we grow old?

“In evolution that would not be stable, because eternal youth does not abolish mortality. Sooner or later something will get you: an accident, a new epidemic, and attack by terrorists, or whatever. A mutation that would confer some slight advantage in our early child bearing years that allowed us to leave more offspring might well be favored even if it causes us to drop dead at an older age.”—George C. Williams in Roes, 1998

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### The Evolution of Multicellular Animals

“Before there were single-celled or multicellular eukaryotic consumers, the Earth’s ecosystem was relatively simple. Because the primary photosynthetic producers—cyanobacteria and eukaryotic algae—did not suffer predation, they multiplied in aquatic settings to an extent that was limited only by the supply of nutrients essential to their growth. Seas and lakes were, in effect, saturated with algae—a situation that may have slowed evolution by leaving very little room for the origin of new species. Although the first organisms to feed on algae must have been animal-protists, today these forms are feeble in this role in comparison to the multicellular animals, which because of their size can consume algae rapidly. Thus, the origin of eukaryotic consumers, especially multicellular animals, added a new trophic level to many aquatic ecosystems."—Stanley, 1989

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## The Evolution of Life and Energy

- From the evolution of photosynthesis that led to increasing oxygen in the atmosphere;

- to the evolution of aerobic respiration in heterotrophic prokaryotes—like mitochondria—that could consume the carbohydrates produced by autotrophic prokaryotes;

- to the evolution of eukaryotic life with its abundant energy from mitochondria;

- to the evolution of sexual reproduction that provided genetic mixing for large, complex and slowly reproducing eukaryotes;

- to the evolution of heterotrophic multicellular life that could effectively consume abundant autotrophic eukaryotic life;

- we see life evolving mechanisms to take advantage of new sources of energy.

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## Relative Time

- On the order of 2000 million years elapsed between the origin of life on Earth and the evolution of the first complex eukaryotic protists. This represents two billion years of prokaryotic evolution, half of the history of life.

- Almost 1000 million years elapsed between the origin of complex eukaryotes and the first evidence of sexual reproduction.

- It was then only from 100 to 400 million years between the evolution of sexual reproduction in eukaryotes and the evolution of the first multicellular organisms—creatures like us.

- So for approximately 3000 million years of the history of life on Earth all life-forms were single cell. This is 75% of the total history of life.

- And fully 4000 million years elapsed between the formation of the Earth and the beginning of the Phanerozoic eon 550 m.y.a.—our eon.

- In stark contrast, all of recorded human history occupies only 0.005 million years.

That is 0.00000125 of the history of life on Earth.

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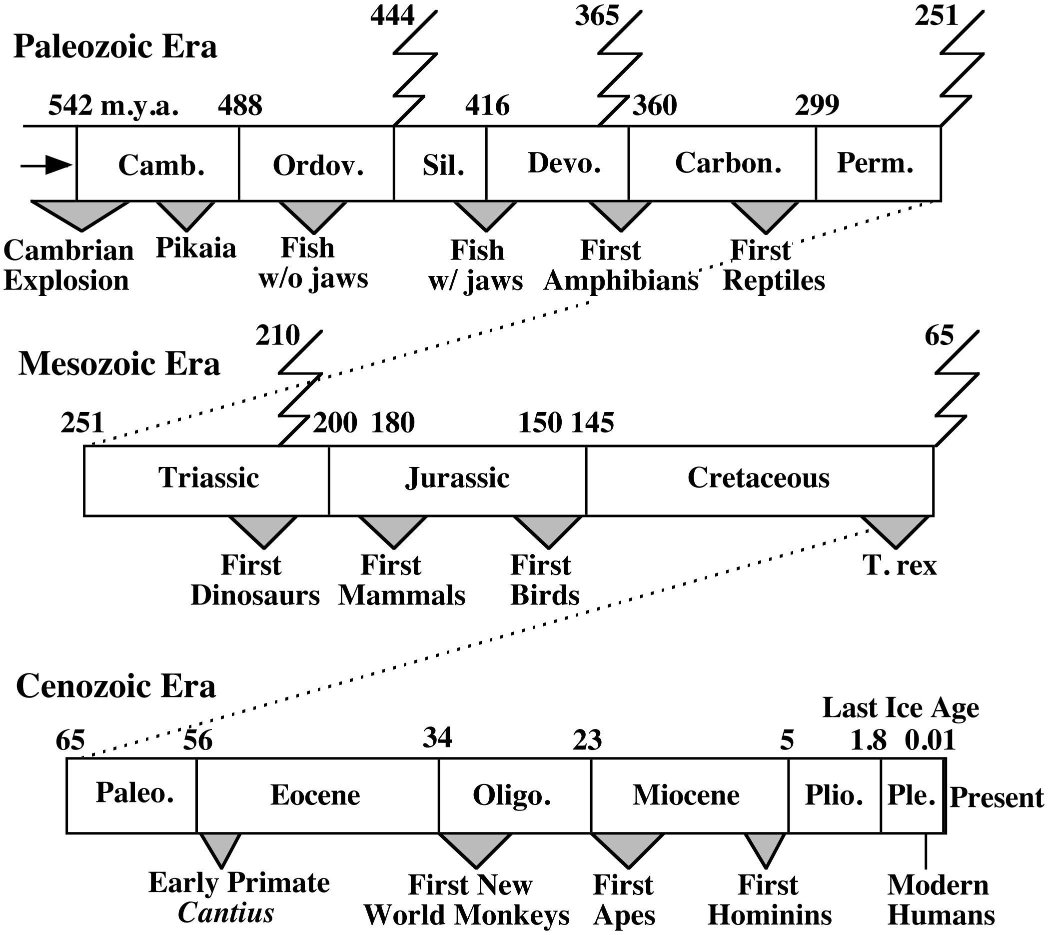
## The Phanerozoic Eon



## Major Events in the Phanerozoic Eon

1. the Cambrian adaptive radiation—the evolution of all of the basic body plans of animals including the evolution of the notochord
2. the mass extinction event at the end of the Ordovician
3. the colonization of land by plants and then insects in the Silurian
4. the adaptive radiation of fish in the Devonian
5. the mass extinction event during the late Devonian
6. the evolution of the first land vertebrates, the amphibians, during the late Devonian
7. the evolution of internal fertilization and the amniotic egg with the first reptiles in the Carboniferous
8. the mass extinction event during the late Permian
9. the adaptive radiation of the dinosaurs in the Mesozoic
10. the mass extinction event during the late Triassic
11. the evolution of the first true mammals in the early Jurassic
12. the mass extinction event at the end of the Cretaceous
13. the adaptive radiation of mammals, including primates, in the Cenozoic

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## The Five Mass Extinction Events of the Phanerozoic Eon

(after Benton, 2003)

1. **End Ordovician ~ 440 m.y.a.** with a loss of at least 50% percent of species.

2. **Late Devonian 370 to 360 m.y.a.** with a loss of at least 50% percent of species.

3. **End Permian 251 m.y.a.** with a loss of 80 to 95 percent of species.

4. **Late Triassic ~ 210 m.y.a** with a loss of at least 50% percent of species.

5. **End Cretaceous 65 m.y.a.** with a loss of at least 50% percent of species.

Three things happened in all the mass extinctions of the Phanerozoic.

A. many species became extinct, generally more that 50%.

B. the extinct forms span a broad range of ecologies, and they typically include marine and non-marine forms, plants and animals, microscopic and large forms

C. the extinctions all happened within a short time, and hence relate to a single cause, or cluster of interlinked causes.

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## Adaptive Radiations

A new evolutionary adaptation may lead to a new level of evolutionary stability that, because of its inherent potential to provide new opportunities for life, gives rise to an adaptive radiation of new species. Multicellularity was such an evolutionary adaptation, and it gave rise to the explosive radiation of animal evolution known as the Cambrian Explosion.

The history of the Phanerozoic Eon is marked by such adaptive radiations of species. The events that have driven these bursts of rapid evolution follow a pattern of abiotic change that leads to mass extinction events that, in turn, set the stage for a new round of adaptive radiation by a new group of species. The major abiotic causes for such mass extinctions are associated with **plate tectonics** and **meteorite impacts**.

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## Essay—The Effects of Meteorite Impacts

“The effects of an impact on life depend in a qualitative way on the impact energy. The smallest space debris to hit Earth’s atmosphere is slowed to benign speeds by gas drag or vaporized before it hits the ground. The largest impactors can melt a planet’s crust and eliminated life entirely. Strong iron impactors ranging in size from that of a car to that of a house may hit the ground at high velocity, killing living beings in their path. The rocky bolide that exploded over Tonguska, Siberia, in 1908 was about the size of a football field; it produced a blast wave that knocked over trees tens of kilometers away. An impactor a few kilometers in size would throw enough dust into the upper atmosphere to substantially darken the sky for much of a growing season. The threat of such an impactor to human food supplies has led NASA to initiate a program to detect all near-Earth asteroids (NEAs) larger than about 1 km.

Mass extinctions (such as that at the K/T boundary) result from even larger impacts, which load the atmosphere with dust and chemicals (from vapor and pulverized matter originating in both the impactor and the crater ejecta). Radiation from high-velocity ejecta re-entering the atmosphere may cause global fires. Even larger impacts fill the atmosphere with enough hot ejecta and greenhouse gases to vaporize part or all of the planet’s oceans.” —Lissauer, 1999

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## The Cambrian Explosion—Before and After

What major adaptive features were in place before the Cambrian explosion, and what major evolutionary adaptations arose during the event?

There are three points to be made:

Point 1—What didn't change was that before and after the event all life lived in the oceans.

Point 2—The major features that were already present:

eukaryotic cells
sexual reproduction
multicellular organisms

Point 3—The major evolutionary adaptations that arose were the body plans of all the major phyla of animals:

- radial symmetry (cnidarians—the jellyfish)
- a tube-like body (nematode round worms)
- segmentation (annelid worms)
- calcareous shells (mollusks)
- the exoskeleton and bilateral symmetry (arthropods)
- the notochord (vertebrates)

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## The Advantages of being Multicellular

1. cell specialization
2. size as it increases mobility
3. getting food—size as an advantage for predators
4. not being food—size as a defense against predators

This sets up the predator / prey arms race.

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## Unit Seven: Vertebrate Evolution

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### Vertebrate Evolution in the Early Paleozoic

From Mother Lamprey to Jaws—the adaptive radiation of fish

Lungs and Four Legs—the evolution of Amphibians

Tetrapods the first Land Vertebrates

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### Vertebrate Evolution in the Late Paleozoic and Mesozoic

**Amphibians to Reptiles**

Internal Fertilization, the Amniotic Egg, and a Water-Tight Skin

**The Adaptive Radiation of Reptiles**

from Scales to Hair and Feathers

Therapsids to Mammals

Dinosaurs to Birds

Ectothermy to Endothermy

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### T. Rex and the Crater of Doom

The Mass Extinction Event at the End of the Cretaceous 65 m.y.a.

The End of an Era

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## Essay—The Chicxulub Crater

The Chicxulub crater is often cited as one of the best preserved records of an Earthly cosmic disaster. Discovered only in the 1970s by oil drilling teams, the crater was relatively unstudied until the 1990s, when scientists linked it to theories that asteroid impact may have spelled the dinosaurs' doom.

The asteroid impact near the tip of Mexico's Yucatan peninsula about 65 million years ago has long been believed to be a potential cause for the death of the dinosaurs, which vanished at roughly the same time.

That impact was like nothing recorded in human history. Millions of years before humans even existed, a huge meteorite measuring about 6 miles across and weighing perhaps billions of tons crashed into the planet in a ball of fire, shrouding the Earth in a dense cloud of dust that blocked out sunlight and sent temperatures plummeting.

Estimates now put the crater's size at about 125 miles in diameter, indicating a force of impact equivalent to an earthquake about 10,000 times stronger than the one that leveled San Francisco in 1906 and equal to the explosive force of hundreds of atomic bombs.

About 60 percent of all recorded species on the earth disappeared around the time the meteorite struck. On land, scientists believe nothing larger than a dog survived.

While researchers agree that vast amounts of dust and debris were sent shooting into the atmosphere, the actual mechanics of how this may have caused a global catastrophe are still under study. One problem is that environmental effects of the impact would have to have been felt worldwide in order to account for the planetary extinction of so many species.

Scientists now hope that examination of core samples from the crater will give a better understanding of the chemical make-up of the material involved—specifically, by indicating how much sulfur- and carbon-bearing rock was sent hurtling into the sky. This will tell a lot about how the carbonates and sulfates of the limestone sediments of the ancient sea floor the asteroid struck react to high impact pressures.

Limestone rock evaporated by the impact might have clogged the atmosphere with floating sulfur particles, causing a "nuclear winter" by blocking sunlight essential to plant growth, removing the essential first link in the worldwide food chain.

Sulfur particles falling into the ocean could also have transformed the world's seas into vast, acidic pools, killing off much of the sea life.

Following this disaster, immense amounts of carbon dioxide released from vaporized limestone could have contributed to a secondary greenhouse effect, sending temperatures soaring and killing off much of the remaining life on the planet.

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**Unit Eight: Human Evolution**

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## Major Trends in Hominin Evolution

1. **habitat**—from gallery forest, to open forests, to savanna
2. **locomotion**—from brachiation to knuckle walking, to first bipedal, to obligate bipedal
3. **diet change**—tooth enamel and size—soft food, to coarse food, to soft food
4. **intestine length**—from long to short—from vegan to carnivore
5. **sexual dimorphism**—from a lot to little
6. **cranial size / body size ratio**—three spurts: *H. rudolfensis*, *H. heidelbergensis*, *H. sapiens*

### Points:

A. 5 m.y.a. last common ancestor of humans and chimps—chimps are not our ancestors.

B. Bipedalism evolved first—*Australopithecus anamensis* still had a chimp size brain.

C. *Homo ergaster* evolved a modern body but no significant increase in brain size to body size ratio.

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## Essay—On the Origin of Modern Humans

The story of human history during the last Ice Age is slowly emerging through the agency of modern science and, as is the nature of science, in a most unexpected way. The elements of the story are being put together by anthropologists, paleontologists, climatologists, archaeologists, and population geneticists. What was unexpected is that modern molecular biology has provided a growing body of evidence that answers many of the long standing questions about our origins. When did modern humans originate? Where did it happen? When did modern humans begin to spread throughout the old and new worlds? Are we related to the Neanderthals? What is the population history of human beings? How closely are we genetically related to each other? These and many other questions are now being deciphered and for the first time we can begin to piece together the history of our origin.

### In the Beginning—When did modern humans originate?

"Recent research based on the full sequence of mtDNA reduced the estimate [for the origin of anatomically modern humans at about 200,000 y.a.] to slightly less than 150,000 years ago."—Cavalli-Sforza, 1998

### The Garden of Eden—Where did we come from?

"Population genetic studies are in approximate agreement with archaeological observations indicating that anatomically modern humans (i.e. similar, as far as bone morphology goes, to living humans) are found in the past 100,000 years exclusively in Africa, or very close to it (the Middle East) and spread from it to the other continents."—Cavalli-Sforza, 1998

### What was the size of the "founder" population of modern humans?—Rhode Island in Africa

"The number of our ancestors just before the expansion ("origin") of modern humans was small. Many genetic systems provide reassuringly congruent estimates: all indicate that the approximate population size was on the order of 10,000 breeding individuals [this is 20,000 individuals total see Felsenstein 1971]." "Although the size of this population must have fluctuated over time, it was often reduced to the level of several thousands of adults. Such a population would have occupied an area the size of Rhode Island rather than a whole continent". —Harpending, 1998

### Out of Africa

"A current estimate [for the genetic separation of Africans and non-Africans] gives a value closer to 60,000 y.a. with a standard error of close to 20% [72,000 y.a. to 48,000 y.a.]." — Cavalli-Sforza, 1998

### Why did modern humans spread out of Africa?—The Walker Predator Density Hypothesis

If you invent a new way of hunting, be it cooperation, new and better weapons, modern language, or any combination of these, then you are faced with the predator density problem (Walker & Shipman, 1996). That is, as you become a more efficient predator, you run the risk of killing off your prey species. The only long term solution for hominids, in this case, is to reduce population density per unit area. This puts tremendous pressure on populations to disperse in search of new prey. In other words, increased hunting efficiency leads to a form of competitive release by enforced range expansion. The spread of modern humans out of Africa (and Homo erectus before them) resulted from competitive release brought about by qualitative increases in hunting efficiency. But several factors had to be available. You had to have someplace to spread to, for example. Modern humans originating in Africa, as they did, had all of Eurasia to spread into reaching Australia between 60,000 and 53,000 y.a., Europe by 40,000 y.a., and eventually, by way of the Bering land bridge, all of the Americas.

### Relatives?—the Neanderthals

A dramatic study done in 1998, where traces of mitochondrial DNA were extracted from the first Neanderthal fossils ever found, has provided compelling genetic evidence that we are not closely related to the Neanderthals. "More than 380 nucleotides in region 1 of the D loop [of mtDNA] were studied. The average difference among pairs of modern humans is 8.0, while the range of the difference between a modern human and Neanderthal is 22-36. These results put Neanderthal out of the modern human line, and confirm that it is most probably completely extinct." (Cavalli-Sforza, 1998) In March of 2000, a second report of Neanderthal mtDNA being extracted was published in the journal *Nature* (Hoss, 2000). This second mtDNA analysis was from a Neanderthal found in the northern Caucasus dated to 29,000 years ago. "...it provides invaluable corroboration for the authenticity of Neanderthal mtDNA sequences."(Hoss, 2000)

These DNA studies are supported by fossil and archaeological evidence in showing that by 28,000 y.a., approximately ten thousand years after modern humans had arrived in Europe, the Neanderthals were extinct. Thus the Neanderthal found in the northern Caucasus may be one of the last members of this sister species to modern humans.

### What is the demographic history of the prehistoric human population?

Two major periods of exponential expansion in the population of early modern humans can be identified. The first resulted from modern humans spreading out from their homeland in Africa. The second is the result of the invention of agriculture.

During the Middle Paleolithic (200,000 to 44,000 y.a.) "early human populations were exceptionally small, even by later Paleolithic standards and [it appears] that early Middle Paleolithic humans did not spend much time foraging in any one vicinity." (Stiner, 1999) At some point, however, early modern humans in Africa developed new hunting technologies which lead to their expansion out of Africa ~ 60,000 years ago. This expansion into virgin territories, together with new hunting technology, caused the first period of exponential growth in human numbers. The human population did grow exponentially during this period, however densities were kept low by the combination of reliance on hunting and the violent climate swings of the Late Pleistocene (see below).

The second major pulse in human population growth is associated with the invention of agriculture. But if you have been successful as hunters and gathers for thousands of years, why invent agriculture? The answer lies in the combination of three events.

First, the climate changed 11,500 y.a.. Why didn't humans invent agriculture a hundred thousand years ago? The first modern humans were identical to us and, therefore, surely intelligent enough to do so. Why did the invention of agriculture and the population explosion that followed have to wait until 12,000 to 10,000 years ago? Part of the answer is in the weather. All during the Pleistocene Ice Age violent weather was the norm, and not until the interglacial climate shift 11,500 years ago did the violent swings in climate settle down to our present calm state. Peter Ward provides this picture:

> "The analysis of oxygen isotopes from the Greenland ice cores have shown that the climate over the past 250,000 years has changed frequently and abruptly; the magnitude of the global temperature changes has been far greater, and their intervals far shorter, than anyone imagined. Dr. J. White of the University of Colorado, noted in a recent summary that between 200,000 and 10,000 y.a., average global temperature had changed as much as 18° F in a few decades. The current average global temperature is 59° F. Imagine that it suddenly shot up to 75° F or sank to 40° F in a century or less. At a minimum, these sudden changes would create catastrophic storms of unbelievable magnitude and fury. Yet such changes were common until 10,000 years ago. Imagine a world where storms that dwarf Hurricane Andrew lash the continents not once a century but several time each year, every year. Imagine a world where tropical belts are suddenly assaulted by snow each year. This was our world until 10,000 years ago, when, according to the studies of the Greenland ice cores, the unimaginable happened: The sudden shifts in the weather stopped."—Ward, 1997

Second, modern humans in area after area reached their density limit as hunters. By the Upper Paleolithic (44,000 to 19,000 y.a.) hunting pressure had forced people's attention from slow moving prey to fleeter prey types. This is, after all, what happens when you spread out and then kill off your preferred (which usually means easier to catch) prey species. Once your population spreads out and fills all available habitats, however, you can't do it again (this is the notion of demographic packing). So if your population increases, it must increase your density per unit area, thereby putting even greater pressure on food resources. "Mobility was the preferred solution to local resource scarcity throughout much of prehistory. Any loss of mobility options is a grave matter for people who live by hunting and gathering. The changes in prey species during the Mediterranean Paleolithic nonetheless indicate demographic packing and associated reductions in mobility."—Stiner, 1999

And third, by 11,000 y.a. modern humans had killed off the Pleistocene megafaunas, the mammoths, mastodons and ground sloths along with many other large species, of both the old and new worlds. In North America 73% of all genera weighing more than 100 pounds went extinct between 12,500 to 11,000 y.a., not long after humans arrived on the continent (Ward, 1997; Flannery, 1999). "But Australia suffered the most severely of all the continents, losing every terrestrial vertebrate species larger than a human," (Flannery, 1999). Most telling of all is that the Australian extinctions again coincided with the arrival of humans, only this time at around 50,000 years ago, at least 30,000 years before humans reached the Americas.

On the one hand the extinction of the Pleistocene megafauna put selective pressure on early human hunters to find other food sources, at the very least smaller game, whereas the climate change allowed that new food source to be cultivated plants. An example in support of this hypothesis comes from Pringle:

> "In a layer dated to at least 13,000 y.a. the [rice] phytoliths show that hunter-gathers in the cave were dining on wild rice. But by 12,000 y.a., those meals abruptly ceased—Zhao suspects because the climate became colder and the wild grain, too tender for such conditions, vanished from this region. Studies of the Greenland ice cores have revealed a global cold spell called the Younger Dryas from about 13,000 to 11,500 y.a.. As the big chill waned, however, rice returned to the region. And people began dabbling in something new around 11,000 y.a.—sowing, harvesting, and selectively breeding rice."—Pringle, 1998

The invention of agriculture caused the second period of exponential growth in the human population by allowing increases in population density per unit area rather than range expansion. Note that new studies of the origin of agriculture clearly place the origin at the interglacial climate shift 11,500 years ago .

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## Two Possible Histories of our Origin

A summary of the preceding essay might read as follows.

Sometime around 150,000 years ago, somewhere on the continent of Africa, the morphology of an isolated population of approximately 20,000 early humans became indistinguishable from that of humans today. This population over time developed more efficient hunting techniques that produces two outcomes. The population increased but was also forced to expand its range. As time passed this combination lead to modern humans spreading out from Africa, first to Eurasia, then to Australia (~ 50,000 y.a.) and on to Europe (~ 40,000 y.a.), and finally to the new world (20,000 to 14,000 y.a.). Once the world was covered with modern humans the pressure of their hunting caused the extinction of the Ice Age monsters, the mammoths, woolly rhinos, giant ground sloths and many other almost mythological creatures. And along with the Ice Age megafauna our nearest relative the Neanderthals also went extinct. But still the pressure of increasing population did not end. Instead new sources of food would be found, this time from the earth itself. But fate also had to intercede. The violent climate of the Ice Age ended as if on cue.

All of these forces, demographic packing, the extinction of big game, the end of violent climate swings, and increasing population pressure, may have combined to lead to the invention of agriculture in the old world between 12,000 and 10,000 years ago. But with that invention the world changed forever as the human population began, slowly at first, its incredible explosion in numbers. Today, it is increasingly clear that we are near the end of that explosion. Although we still do not know what will bring it to a halt, what does seem certain is that the outcome will be known within the lifetime of children born today.

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## From *What We all Spoke When the World Was Young* by Nicholas Wade

“In the beginning, there was one people, perhaps no more than 2,000 strong, who had acquired an amazing gift, the faculty for complex language. Favored by the blessings of speech, their numbers grew, and from their cradle in the northeast of Africa, they spread far and wide throughout the continent.

One small band, expert in the making of boats, sailed to Asia, where some of their descendants turned westward, ousting the Neanderthal people of Europe and others east toward Siberia and the Americas.

These epic explorations began some 50,000 years ago and by the time the whole world was occupied, the one people had become many. Differing in creed, culture and even appearance, because their hair and skin had adapted to the world’s many climates in which they now lived, they no longer recognized one another as the children of one family. Speaking 5,000 languages, they had long forgotten the ancient mother tongue that had both united and yet dispersed this little band of cousins to the four corners of the earth.

So might read one possible account of human origins as implied by the new evidence from population genetics and archaeology.”—Wade, 2000

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## Essay—Human Evolution

"Our human bodies record a sequence billion of years longer than human culture. Nested like Russian dolls are features that we share with more and more organisms the deeper we probe. As humans, we have uniquely large brains and upright posture; as primates, fingernails and stereoscopic vision; as mammals, hair, warm blood and milk-fed young; as amniotes (the group that includes mammals, birds, and reptiles) internal fertilization and the ability to reproduce ourselves outside a watery environment. With other vertebrates we share a rigid internal skeleton. All animals have tissues, and all of us collect our carbon and energy from organic compounds derived from all those plants, algae, and bacteria that can use either chemical energy or light to manufacture their own supplies out of non-living raw materials. Like almost all organisms except bacteria, we have cells with nuclei and chromosomes, organelles, and an oxygen drive. In common with every living thing we have DNA, genetic blueprints, and metabolism—the equipment to absorb, dismantle, and exploit useful molecules.

This sequence is a journey proceeding out of time. Listed so simply, it is apt to sound like the flow of a single force with an inevitable outcome. Yet the long-range order that we see with hindsight is the outcome of a blizzard of causes blowing this way and that. It shows that evolution has not worked like a single steamroller headed in some purposeful direction, but as a set of improvisations and haphazard events, constantly reinventing itself. Rather than redesigning the fundamental machinery of life, evolution appears to have tinkered with the most variable and possibly least essential details. When such changes happen at the right time and place, they may prove useful as conditions change. Like our fellow species, we are a ramshackle collection of these useful adaptations, with layer tacked on to underlying layer, each one reflecting the successful inventions of bygone times."—J. John Sepkoski Jr. in Gould (ed.), 1993

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## To Make a Human Being

4000 m.y.a. the evolution of the cell, DNA, and cellular metabolism

2000 m.y.a. the evolution of aerobic respiration and eukaryotic cells

1100 m.y.a. the evolution of sexual reproduction

700 m.y.a. the evolution of multicellular animals

520 m.y.a. the evolution of the notochord

360 m.y.a. the evolution of terrestrial tetrapods

300 m.y.a. the evolution of internal fertilization and the amniotic egg

180 m.y.a. the evolution of hair, warm-bloodedness, and milk to suckle young

55 m.y.a. the evolution of fingernails and stereoscopic vision

4.1 m.y.a. the evolution of walking upright—bipedalism

2.5 m.y.a. the evolution of stone tool making

1.8 m.y.a. the evolution of the genus *Homo*

0.15 m.y.a. the evolution of anatomically fully modern humans

0.06 to 0.04 m.y.a. the evolution of modern language

0.005 m.y.a. the invention of writing

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## How can we organize our knowledge of the natural world?

1. There is a chronological sequence in which the universe developed.
2. Levels of stable types of phenomena are built upon other more basic levels.
3. These levels of stable phenomena have accumulated through time.
4. Life on Earth is one of these natural levels of stable phenomena.
5. Evolution can explain the development of all these levels of stability.

Life on Earth is an “effectively” closed historical system, an unbroken physical chain of reproduction and changing generations. There is a necessary chronological sequence in which life developed as levels of stable phenomena built upon other more basic levels. These levels of stable phenomena in the history of life have accumulated through time to produce “endless forms most beautiful and most wonderful”, including ourselves. And it is the consilient power of the theory of evolution by natural selection that it can explain how this happened.

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## Part Four: Biology and Society

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### Science & Ethics

How does scientific knowledge affect social, ethical questions?

What is the nature of human nature?
Are we intrinsically good or are we inherently bad?

If our genetic heritage determines how we are, at least in part,
should we accept our nature or oppose it?

What of human violence?
Is violent aggression "wrong"?

What of human fecundity?
Is a mother's love for her child "right"?

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Natural fecundity always leads to over production of offspring beyond what the environment can support.

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Is it possible that the world we are adapted for no longer exists, and that we are now genetically maladapted to the modern world we live in?

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### Freedom of Action & Control

Moral responsibility can arise only when there is freedom of action and the ability to control the outcome of relevant events. Thus, there are two aspects in assessing moral obligation. The first is that we must be free to act upon our ethical considerations. The second is that our actions must be able to change the course of events. We must be able to control the outcome of events to have moral responsibility, for no moral entity can logically be held responsible for anything that is beyond their control. Thus, *control*, itself, is the logical first principle for determining moral responsibility.

*The most significant change in our world in the last four hundred years is that science and technology have immensely extended our control over natural events. This extension of control has extended our moral obligations in directions undreamed of by our ancestors. It is, therefore, the fundamental task of our age to analyze and come to understand how this extension of control over the natural world has changed our moral obligations.*

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## How has science changed our world?

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World Population projections show that by the year 2050 the human population will reach 9 billion. Today the human population is over 6.6 billion.

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Over production coupled to variation that can be inherited leads to differential reproductive success which leads to adaptation to local environments.

What does "differential reproductive success" mean if not that some will fail and others will win in the raw, amoral competition of life.

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"The universe we observe has precisely the properties we should expect if there is, at bottom, no design, no purpose, no evil and no good, nothing but blind, pitiless indifference."

Richard Dawkins from his book *River out of Eden* (1995, 133)

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### Adaptation

Evolution by natural selection does not lead to optimal adaptations. It produces only historically constrained answers to past questions. What worked in the past was cobbled together from what was genetically available and has no guarantee of working in the future. Evolutionary adaptations are always a gamble that future conditions will be similar to the past. In reality—

*the only adaptation natural selection "selects" is reproductive success.*

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"Let us understand, once and for all, that the ethical progress of society depends, not on imitating the cosmic process [evolution by natural selection], still less in running away from it, but in combating it."

Thomas Henry Huxley from his essay *Evolution and Ethics* in Paradis (1989)

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In the end, it may be true that the process of natural selection, itself, is the greatest cause of evil.

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## Human Population Increase

Based on genetic evidence, at some point in the Late Pleistocene the ancestral population of humans dropped to a low of ~ 20,000 individuals (Cavalli-Sforza, 1998; Harpending, 1998). From this Late Pleistocene population modern humans spread throughout the globe and then invented agriculture so that by the year 1 A.D. the human population had reached 1/4 billion. It then took—

from 1 A.D. to 1600 — to reach 1/2 billion (1600 years doubling time)
from 1600 to 1830 — to reach 1 billion (230 years doubling time)
from 1830 to 1930 — to reach 2 billion (100 years doubling time)
from 1930 to 1960 — to reach 3 billion (30 years to add a billion)
from 1960 to 1974 — to reach 4 billion (14 years to add a billion)
from 1974 to 1987 — to reach 5 billion (13 years to add a billion)
from 1987 to 1999 — to reach 6 billion (12 years to add a billion)

(after Cohen 1995)

World population projections also show that by the year 2050 the human population will reach 9 billion. (Lutz, 2001) This will be from 20,000 to 9,000,000,000 or more than a **450,000** times increase in population in a period of time that is, when compared to the history of life on Earth, a geologic instant.

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- **Point:** The whole point is that we are doing exactly what natural selection has programmed natural levels of fecundity to achieve—increase our population until the environment stops us. The reason our population has exploded results from a form of competitive release. First improved hunting methods, then agriculture, and finally science and technology have released us from the population constrains of disease and famine and we have exploded across the Earth.

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## The Scientific Consensus

Starting in 1992, and continuing to the present some 1,670 scientists, including 104 Nobel laureates, have signed *The World's Scientists Warning to Humanity* on population. In 1993, fifty-six of the world's scientific academies (including the U.S. National Academy) came together in a "Science Summit" on world population. The conference had as its primary goal the formulation of a statement to be presented at the International Conference on Population and Development in 1994. The consensus opinion of both these efforts is expressed in the following statements.

"Human beings and the natural world are on a collision course. Human activities inflict harsh and often irreversible damage on the environment and on critical resources. If not checked, many of our current practices put at serious risk the future that we wish for human society and the plant and animal kingdoms, and may so alter the living world that it will be unable to sustain life in the manner that we know. Fundamental changes are urgent if we are to avoid the collision our present course will bring about."

"Pressures resulting from unrestrained population growth put demands on the natural world that can overwhelm any efforts to achieve a sustainable future."

"No more than one or a few decades remain before the chance to avert the threats we now confront will be lost and the prospects for humanity immeasurably diminished."

(For the full text of these documents see Ehrlich 1996, Appendix B, pages 233-250.)

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## Biodiversity Today: The Sixth Extinction

"Humanity has initiated the sixth great extinction spasm [in the history of life], rushing to eternity a large fraction of our fellow species in a single generation."

Today, then, is the sixth extinction.

The term, as shown by this quote, was first used by E. O. Wilson in his book *The Diversity of Life* (1992).

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## Estimates of the Current Extinction Rate

Peter Raven, Director of the Missouri Botanical Survey and one of the first scientists in America to draw attention to the biodiversity crisis, estimates that by the end of the year 2200 [two hundred years from now] 67% of all the species now living will be extinct (Ward 1997, 207).

The textbook *Life* (5th ed.) states: “Moreover, even the lowest estimates of current extinction rates predict that at least 10 percent of Earth’s species are likely to become extinct during the next twenty years. Some estimates predict the extinction of 50 percent of Earth’s species during the next 50 years.”—Purves 1997, 1224

Estimates of the natural background extinction rate cluster around 10 species per year for all species. The current extinction rate is now estimated to be a 1000 times that natural rate of extinction.

• *The bottom line is that we could lose between 1/3 and 1/2 of all species within the next hundred years (Pimm 2001).*

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As Peter Raven puts it: “At the time *Homo sapiens* developed agriculture in a number of widely scattered centers, some 10,000 years ago, there were fewer than five million of us throughout the world. Now we number over six billion. We consume, waste or divert about half the total primary net photosynthetic productivity on land; we use about half the total supplies of freshwater and affect directly some two thirds of the planet’s surface. Over the past 50 years, while our total population has grown by 3.5 billion people, we have lost a quarter of our topsoil and a fifth of our agricultural lands, changed the characteristics of the atmosphere in important ways and cut down a major part of the forests. It is no wonder that we are driving to extinction, and will drive over the next century, such a high proportion of the other organisms that live with us on Earth, thus limiting our own material and spiritual prospects substantially.”—Raven, 1998, 100

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## The Upshot

What then are the realities of our relationship to the natural world? I submit it is something akin to the relationship Jared Diamond describes between groups of early agriculturists—kill everybody except those you grew up with and only stop killing when somebody stronger than you tells you to (Diamond, 1997).

Humanity simply does not let nature stand in the way of what it wants. The results of this are predictable—we are wiping out the other life-forms on Earth at an ever increasing rate. The scale of this slaughter is comparable to, if not greater than, the scale of species extinction that occurred during the five recognized mass extinction events in the history of life.

It is, therefore, a valid question to ask: Are there any ethical relationships between humanity and other species? And if there are, when will we accept our moral obligations toward other life-forms—before or after we drive most of them to extinction?

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E. O. Wilson from *The Diversity of Life* (1992)

"Four splendid lines of Virgil came to mind, the only ones I ever memorized, where the Sibyl warns Aeneas of the Underworld:

The way downward is easy from Avernus.

Black Dis's door stands open night and day.

But to retrace your steps to heaven's air,

There is the trouble, there is the toil . . ."

"We do not understand ourselves yet and descend farther from heaven's air if we forget how much the natural world means to us. Signals abound that the loss of life's diversity endangers not just the body but the spirit. If that much is true, the changes occurring now will visit harm on all generations to come."

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## Why do science?

"The extreme novelty of humans as the dominant force on this planet is as surprising as is our current rate of destruction of our own habitat and that of the Earth's other life forms. This disregard is all the more striking since, in geological terms, our species has only recently departed from its 'place in nature'. The full implications of our derivation by the random processes of biological evolution in a mere 5 million to 7 million years from an animal much like a chimpanzee have yet to be incorporated in any manner into the fundamental beliefs or institutions of our own, or in fact, any society. In its very success, our species has raised grave problems that demand new kinds of solutions. Will we, by better understanding the processes that made us what we are, grow in capacity to solve the frightening problems of the future arising from our very selves?"

Elwyn L. Simons from his article *Human Origins* (1989)

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