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Teaching the Epic of Evolution

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http://www.tufts.edu/as/wright_center/eric/ericpage.html

The Early Years

While a student at Harvard in the early 1970s, I aimed to enroll in the course that I had always wanted to take, but found that it didn't exist. I was seeking a broad survey course that cut across the boundaries of all the natural sciences, not only because I was unsure which of the sciences I might like later to study in depth, but also because I was personally seeking an overarching, integrated worldview. I was eager to make sense of all that I saw around me in the air, land, sea and sky, and I was especially struggling to place myself into the big picture of Nature writ large.

Sadly, nearly everyone I met 40 years ago—much as still the case today—was into "their own thing." Peers studied narrow disciplines, faculty researched specialized domains, and few people showed much interest in others' fields of knowledge. That universities are so lacking in universal learning and teaching was my biggest disappointment at the time, and still is. There had been earlier exceptions: Observatory director Harlow Shapley had taught a wide survey on "cosmography" from the 1920s to the 1950s, and (my predecessor) Carl Sagan had taught "life in the universe" to big crowds in the 1960s; but by the time I arrived as a student, Shapley was dead, Sagan banished, and the broad course I sought was nowhere to be found in the Harvard catalog.

Nearly a decade later, when I was appointed to the Harvard faculty, I was fortunate to be able to co-(re)create that broad survey course along with a senior professor, George Field, who had also long wanted to teach the sciences in integrated fashion. We called the course "cosmic evolution," and we resolved to make it intentionally "a mile wide and an inch deep," regardless of expected criticism. This would be a true survey of the sciences from big bang to humankind—an interdisciplinary sweep across physics, astronomy, geology, chemistry and biology, with social studies included as well. We were unsure if any students would show up.

Within three years, Cosmic Evolution had become the largest science course on the Harvard campus, limited only by the fire codes of the biggest lecture hall. Its immediate acceptance and rapid growth were partly due to our having taken the art of teaching seriously, but mostly because students "voted with their feet." When asked, the students were quick to reply that they, too, were seeking the bigger picture—trying to grasp a larger perspective of all else studied at college, and especially trying to create for themselves a grand system of understanding.

Later Years at Harvard

Even after decades of teaching the epic of evolution, I'm still unsure if I know who I am or how I really fit into the larger scheme of things, but I have found a lifetime of satisfaction exploring the general theme of cosmic evolution, publishing quantitative science to bolster the big-bang-to-humankind story, and especially sharing the details, excitement, and significance of that story with countless folks eager to discover their own worldviews. It has been, for me, the best of all scholarly endeavors: I've selfishly sought to know myself, yet in the process I've apparently helped myriad others to explore themselves and their sense of place in the cosmos.

I have now taught cosmic evolution at Harvard for 28 of the past 35 years since its creation, almost all of those years (as now) alone. For the first few years, I imported many guest speakers, including Steve Gould, E.O.Wilson, George Wald, and several other experts outside my own expertise of physical science. The guest talks were fine as individual appearances, but together they lacked educational continuity. So, when I received a Sloan Fellowship in the 1980s, I surprised my colleagues by using those funds to take a year's leave to learn for myself all the science needed to teach the epic myself. Solo teaching of the course has led to much greater satisfaction personally as it has (pleasantly) forced me to keep abreast of advances in a wide spectrum of subject areas; and it has provided much richer pedagogy and continuity for attending students by having a single person present the bulk of the course content. Appended herein is the syllabus for the course that I currently teach at Harvard. Its multi-media web site is freely accessible at: http://www.tufts.edu/as/wright_center/cosmic_evolution

The subject of cosmic evolution has been at the core of my entire academic career. It's the only thing I know—yet fortunately it includes vast facts, ideas, and implications. As I built the course at Harvard over decades (along with its extensive suite of online-supporting materials), my scholarly research agenda gradually shifted to fully embrace this interdisciplinary topic, and the science-education program that I direct at Tufts' Wright Center has adopted it as our intellectual theme. What started out as a search for single course by a wandering student became a life-long pursuit to understand our world, our universe, and ourselves.

The Course at Tufts

A few years ago, after many unsuccessful attempts to inaugurate a course in cosmic evolution at Tufts (owing to the usual turf battles with specialized faculty), I finally succeeded while co-conspiring with a senior scientist, David Walt, provided that the course was team-taught by representatives from each of the science departments. Today, "From Big Bang to Humankind" (syllabus appended) is a popular offering at Tufts, where I co-teach it with an organic chemist, glacial geologist, developmental biologist, and cultural anthropologist. Such a team effort does lack educational continuity from speaker to speaker, but its decided advantage is that students meet a variety of leading researchers, each of whom has substantial expertise in their respective disciplines. That said, it is sad how interdisciplinarity—in scholarship and in teaching—is still in eclipse in academia, despite all the grandiose statements made by today's college administrators.

Our principal reason for creating this broad survey course at Tufts is that a distinct minority of students there studies natural science. Although about a third of incoming freshman each year indicates intent to major in math/science, less than 10% graduate with a degree in it. It's not much different on many college campuses across the nation—Americans are opting out of science in droves. My contention has been—to the distress of many colleagues—that the science faculty is the main problem here. Blame need not be placed on elementary-school teachers or high-school curricula; rather, it is more likely that college professors, having shirked our duties to teach well, to teach broadly, indeed often to teach at all at introductory level, have abrogated our responsibilities to disseminate the excitement and enthusiasm that we have for our subjects.

Even so, the hope was that such a survey that sweepingly integrates many science disciplines would renew student interest in science—and it most certainly has. The numbers are rising, the students once again voting with their feet. And they are very much inspired by the big picture, as witnessed the other day when, after one of my lectures, a young woman paid me high tribute while remarking with tears in her eyes, "Thank you for helping me remember the love I once had for science." That's the kind of sentiment that makes teaching this stuff for decades worthwhile!

HARVARD COLLEGE OBSERVATORY
Cambridge, Massachusetts 02138

Spring term, 2011

Astro E-8 COSMIC EVOLUTION: The Origins of Matter and Life

Instructor: Dr. Eric J. Chaisson, Research Professor of Physics, Wright Ctr, Tufts University
Associate, Harvard College Observatory, Harvard University

Meets Wed evenings, 7:45-9:45pm, Phillips Audm, Harvard-Smithsonian Ctr for Astrophysics
60 Garden St., Cambridge (across from Radcliffe Quad)

Course Abstract: Evolution of the Universe, from its beginning in a cosmic expansion to the emergence of life on Earth and possibly neighboring planets. Big-bang cosmology, origin and evolution of galaxies, stars, planets, life, and intelligence. Scientific discussion of Nature writ large, from quarks to quasars, microbes to minds. Materials largely descriptive, based on insights from physics, astronomy, geology, chemistry, biology, and anthropology.

Course Description: This broad course combines the essential ingredients of astrophysics and biochemistry to create an interdisciplinary synthesis called “cosmic evolution." Directed mainly toward non-science students, the course addresses, from a scientific viewpoint, some of the time-honored philosophical issues including who we are, whence we've come, and how we fit into cosmic scheme things. Our primary objective is to gain an appreciation for the origin of matter and the origin of life, all the while seeking unification throughout the natural sciences.

The course divides into three segments:

- Part I (~10% of the course) introduces some basic scientific concepts, particularly those physical and chemical principles needed for the remainder of the course.
- Part II (~40% the course) is heavily astronomical, as we use the concept of space to describe the many varied objects populating the Universe, from nearby planets to distant galaxies; this spatial theme serves as an inventory, describing what matter exists throughout cosmos.
- Part III (~50% of the course) uses the concept of time to sketch the central ideas of cosmic evolution—including physical, biological, and cultural evolution—employing a temporal theme to describe how matter and life have changed throughout eternity. Indeed, we shall find that change—*i.e.*, evolution in general—is the hallmark for the emergence of all things, including galaxies, stars, planets, and life.

Throughout our course, we shall concentrate on the formation, maintenance, and destiny of all objects—large and small, near and far, past and future. We shall study in some depth, among other things, the birth of the Universe, exotic quasars, bizarre black holes, relativity theory, 4-dimensional cosmology, the onset of life, intelligence, and society, and the prospects for extraterrestrial life on alien worlds. These and other related topics will be probed to the extent needed to sketch the broadest view of the biggest picture: the newly emerging scientific philosophy of cosmic evolution.

Course Prerequisite: Persistent curiosity. (Knowledge of high-school math is also useful.)

Course R*equirements*:

1. A mid-term exam and a final exam, both generally requiring short paragraph answers. Each exam counts toward $^1/_3$ of the final grade.
2. An 8-page (10-page maximum) term paper, typewritten, counts toward $^1/_3$ of the final grade. This paper should not be written as a book review or technical treatise of some known scientific topic. Rather, it should be a concise, high-quality, analytical, yet non-mathematical treatment of any of the wide-ranging, yet unsolved, subjects introduced in this course. Once a topic has been chosen, the student should read carefully and evaluate critically various competing arguments. *Come to your own conclusion and support it.* Paper topics not covered in the course must be approved by the instructor. Papers are due on the penultimate day of class, 4 May 2011. There will be no extensions. Late papers will be penalized one letter grade per 24-hour interval beyond the deadline.

Section Meeting: An optional period—"the third hour"—for discussion and clarification of course material will be held each Wednesday evening, from 9:45 to 10:30 pm.

Web sites: Three web sites are specifically relevant to this course:

- This web site pertains to the course per se, and includes a copy of this syllabus, course assignments, and other information pertinent to the administration of the course: http://www.tufts.edu/as/wright_center/eric/ericteach.html

- This web site is closely tied to the main textbook for this course, offering much additional material not found in the printed text--images, animations, software, and self-help sections. Access this site via the instructions at the front of the text, or via your browser: http://prenhall.com/chaisson

- This web site contains material directly related to the interdisciplinary subject of cosmic evolution; it is most relevant to the third, evolutionary part of the course: http://www.tufts.edu/as/wright_center/cosmic_evolution

Instructor's coordinates: Eric Chaisson can be reached via any of these routes:

paper = Wright Center, Tufts University, 4 Colby St., Medford, MA 02155
tel = 617.627.5393 (voice) or 617.627.5394 (administrative assistant)
email = eric.chaisson@tufts.edu
chaisson@fas.harvard.edu
web = http://www.tufts.edu/as/wright_center/eric/ericpage.html

CALENDAR OF COURSE EVENTS

Date	*Meeting*	*Readings*
26 January	Course Overview: An Interdisciplinary Approach	1,2 CM; handout; (Pro CE)
I. The Introductory Part: The Essentials		
02 February	Radiation and Spectroscopy: Basic Physics	3,4 CM
09	Telescopes and Geometry: Basic Tools	5 CM
II. The Descriptive Part: A Spatial Theme		
16	The Solar System: Our Home in Space	6,7,8,10,11 CM
23	Sun: Our Parent Star	16 CM
02 March	Stars: Red Giants and White Dwarfs	17,18 CM
09	Galaxies: The Grand Assemblages	23,24,25 CM
23	Mid-term Exam	
III. The Evolutionary Part: A Temporal Theme		
30 March	Universe: Relativity and Cosmology	26,27 CM; 1 CD; (Pro EE)
06	Particulate, Galaxy & Stellar Evolution	19-22 CM; 2 CD; (1,2CE;1-3EE)
13	Planetary Evolution: Birth of Elements & Earth	6,14,15CM; 3,4 CD; (IntrCE;4EE)
20	Chemical Evolution: Origin of Life	5 CD; (3 CE; 5 EE)
27	Biological & Cultural Evolution: Onset of Humans	6,7 CD; (Disc CE; 6,7 EE)
04 May	Future Evolution: Extraterrestrial Life	28 CM; 8 CD; (Epi CE; Epi EE)
11	Final Exam	

Required readings are taken from:
CM = Chaisson & McMillan, *Astronomy Today,* 7th ed., Pearson, 2011
CD = CD-Rom, version 5, *Cosmic Evolution: From Big Bang to Humankind,* 2010

Optional readings (in parentheses above an only recommended) are taken from:
EE = Chaisson, *Epic of Evolution: Seven Ages of the Cosmos*, Columbia Univ. Press, 2006

More technical readings (in parentheses above and meant for students who want to go beyond the level of this course) are taken from:
CE = Chaisson, *Cosmic Evolution: Rise of Complexity in Nature,* Harvard Univ. Press, 2001

Books "CM", "EE", and "CE" are available for purchase in the Harvard Coop or elsewhere in the Square. "CD" is available at: http://www.tufts.edu/as/wright_center/cosmic_evolution

Chemistry 06/ Biology 06 / Physics 06

From the Big Bang to Humankind

Tufts University - Spring 2011

Tue – Thu 3:00pm – 4:15pm (J+ block)

Pearson Chemistry Laboratory, Room 104 - 1 credit

Professors	**Teaching Assistants**
David R. Walt david.walt@tufts.edu (Lead Professor)	Ali Brandeis ali.brandeis@tufts.edu
Eric Chaisson chaisson@fas.harvard.edu	Jenny Geldart Jennifer.Geldart_Flashman@tufts.edu
Andy Kurtz kurtz@bu.edu	**Course Coordinator**
Catherine Freudenreich Catherine.freudenreich@tufts.edu	Meredith Knight Meredith.knight@tufts.edu
Lauren Sullivan lauren.sullivan@umb.edu	

Course Description: Chemistry 0006/ Biology 0006/ Physics 0006: "From the Big Bang to Humankind" will explore the origin and fate of the Universe, the formation of Earth and its structure, the chemistry of life, the evolution and development of complex organisms, and the onset of modern humans. The goal of the course is to understand these topics by examining the scientific evidence and the scientific arguments that enable scientists to have confidence in this knowledge. The course is designed to demonstrate the interdisciplinary nature of science, and to allow students to both reinforce and augment their knowledge of science through learning about the evolution of the universe.

Assignments and Exams: Your grade in this course will be based on two, hour long in-class exams (25% each), one final exam (37.5%) and five homework assignments (12.5%). To help prepare you for the exams, the homework assignment questions will be formatted similar to the questions you will encounter on the exams.

Grading: If you have a **dispute** regarding the grading of an item on a homework assignment or exam, you have one week after the paper has been returned to submit your test or assignment for regrading. After that week, the answer key will be posted on Blackboard and **no regrades will be accepted.** Regrades must be submitted in writing, and the professors and TA will review and regrade all questions on the assignment or exam, not just the one submitted for regrading.

Review Sessions: Between 4:20-4:45pm directly after the class is over, the TA and course coordinator will be available in Room 106 (down the hall from Pearson 104) to answer questions from students regarding the course material. Students may also

Blackboard: Assigned readings and all PowerPoint slides used in class will be posted on Blackboard. An audio recording of the lecture will also be available as a podcast. Details about how to access the podcast are available on Blackboard. Students are encouraged to use the discussion board to post questions and answers and engage in discussion. The discussion board will be monitored by the course coordinator to ensure scientific accuracy.

Readings: All readings will be posted on Blackboard. No texts are required for the course.

<u>Course Schedule:</u>

1 - Thu, Jan 20th - **Introduction of Faculty; Overview of the Course; Explanation of Assignments, Exams and Grades; Discussion of Scientific Evidence**

<u>Astrophysics—Professor Chaisson</u>

2 - Tue, Jan 25th – **Cosmic Evolution: Seeking Unity Among the Natural Sciences**

Question: What is the source of order, structure and complexity in Nature?

3 - Thu, Jan 27th – **Distant Galaxies: The Keys to Cosmology**

Question: How well can we scientifically explore the origin of the Universe?

Homework #1 assigned

4 - Tue, Feb 1st – **Relativity Theory: A Grand Einsteinian Idea**

Question: What evidence do we have regarding the ultimate fate of the Universe?

5 - Thu, Feb 3rd – **The Sun: A Fusion Reactor in the Sky**

Question: How do stars shine, and how well do we understand their basic concepts?

6 - Tue, Feb 8th – **Stellar Evolution: Black Holes & Other Weird Stuff**

Question: What is the origin of the heavy elements comprising our planet and our bodies?

Homework #1 due

7 - Thu, Feb 10th – **Star Formation: Probing Interstellar Space**

Question: How do stars and planets form in the dark realms of the Milky Way?

<u>Geology and Earth Science—Professor Kurtz</u>

8 - Tue, Feb 15th **– Origin of the Solar System, Earth and Moon**

Question: How can we use asteroids, comets, rocks and isotopes to learn about the really deep past of our planetary home in space?

Homework #2 assigned

9 – Tue Feb 17th - **From Continental Drift to Plate Tectonics**

Question: Why did it take geologists so long to figure out what now seems so clear?

10 - Thu, Feb 22nd – **The Hydrosphere and Atmosphere**

Question: How does Earth's climate system work?

Homework #2 due

Thu Feb 24th – no class – substitute Monday's schedule for Thursday

11 - Tue Mar 1st **– Co-evolution of Climate and Life**

Question: How has life on Earth influenced Earth's climate?

12 - Thu Mar 3rd **– EXAM 1—Astrophysics and Geology Exam** – 1 hour

<u>Chemistry—Professor Walt</u>

13 - Tue Mar 8th **– The Biogeochemical Cycle**

Question: Why is carbon dioxide so important?

Homework #3 assigned

14 - Thu Mar 10th **- Atoms, Molecules, and Bonding. Organic Chemistry and the Molecules of Life**

Question: What's so special about carbon?

15 - Tue Mar 15th - **The Origins of Life and The Central Dogma - Molecular Genetics: Proteins, DNA, & RNA**

Questions: The Origins of Life—What is the Evidence? How do molecules transmit information?

16 - Thu Mar 17th**- Biochemistry: Photosynthesis, Glucose, Metabolic Pathways**

Question: How do organisms obtain and use energy?

Homework #3 due

SPRING BREAK - Mar 21st –Mar 25th

Biology—Professor Freudenreich

17 - Tue Mar 29th **– Cells – components and division**

Question: How do cells divide their contents evenly between two daughter cells?

Homework #4 assigned

18 - Thu Mar 31st **–DNA and Chromosomes – the good and the bad**

Questions: How can 2 meters of DNA fit into a 10 µm nucleus? How do chromosome rearrangements cause disease?

19 - Tue Apr 5th – **Genomes – organization and variation**

Questions: What percent of the human genome codes for proteins? How do genomes differ between individuals?

Homework #4 due

20 - Thu Apr 7th – **Mutations and Disease – examples and methods**

Question: How can the consequences of a mutation be determined?

21 - Tue Apr 12th – **Evolution: Finding Darwin in DNA**

Guest Lecturer: Professor Erik Dopman

Question: How are adaptive traits and new species formed?

22 - Thu Apr 14th **– Chem/ Bio Exam**

Anthropology—Professor Sullivan

23 - Tue Apr 19th – **Anthropological and Archaeological Field Methods**

Question: How is the human past investigated?

Homework #5 assigned

24 - Thu Apr 21st – **Early Human Ancestors**

Question: What evidence is there for human evolution?

25 - Tue Apr 26th – **Spread of Early Humans across the Globe**

Question: Where are early humans found after they expand out of Africa?

Homework #6 due

26 - Thu Apr 28th – **The Appearance of *Homo sapiens sapiens***

Question: How closely are modern humans and Neanderthals related?

FINAL EXAM - TBD