Gel. 4: Evolution and the Fossil Record
Course Outline Fall 2021

Course Requirements

1. Students are expected to attend all lectures and discussion sessions.
2. Students may be called upon to answer questions in class, verbally or in writing.
3. Students will write three very short papers on topics to be assigned, though with considerable flexibility as to details. Only peer-reviewed sources may be used as references, and all such references must be cited in full. Plagiarism is strictly forbidden.
4. Students will be given occasional quizzes during the discussion sections.
5. There will be no final exam.

The following is an outline of topics, not a time-calibrated syllabus. The outline provides a general sequence of topics to be covered but retains enough flexibility for changes to be incorporated if needed. There are no examinations in this course. Instead, there will be three papers, two of them a page in length, the third (*the final paper) two pages. Details will be given at the appropriate time.

I. Definition of evolution: descent with modification

II. Evolution as a scientific theory

A. Science as a way of knowing: observations, questions, hypotheses, tests, theory

- Theory: a coherent body of facts, hypotheses and inferences, not a hunch
- Science as approximation to empirical truth, subject to testing, modification and revision
- Categories of science: reductionism vs. holism, experimental, historical/comparative
- Questions of science: what, how, when, where, which, who
- Distinction between description and explanation

III. The theory of evolution: the unifying theory of life

- Phenomena the theory seeks to explain: the sequence of living things in the fossil record; ancestor-descendant relationships; how life and living things arise and change over time; how a good fit between organism and environment comes about; origins of complexity; how our unique species evolved.

- Implications of the theory for other disciplines: understanding human social institutions, economic principles and trends, Earth processes influenced by life, relation between life and climate.

IV. A brief history of the idea of evolution

- Pre-Darwinian views: typology, immutable species created by God, living things as perfect creations.
- Early attempts to make sense of life's diversity: the Linnean system of classification based on similarity; the principle divisions of life.
- Backgrounds and life stories of Charles Darwin and Alfred Russel Wallace: importance of unfamiliar places, deep reading, wide curiosity, questioning the familiar and the unfamiliar.

- What the original architects of the theory did not know: genetics, biochemistry, age of the Earth, plate tectonics, and more.
- Evidence available to Darwin and Wallace: biogeography, comparative patterns of development, the sequence of the fossil record, the geologically active Earth, human-directed selective breeding and domestication, the economics of Adam Smith and Thomas Malthus, organisms as adapted beings and not abstract creations.
- Initial challenges to the theory: the problem of complexity; human uniqueness and the gap between us and other animals; lack of intermediates between major divisions of life; Earth insufficiently old; adaptations passing through unworkable stages as they evolved; existence of an intelligent designer; evolution implying a lack of purpose and meaning; purported (but incorrect) violation of the second law of thermodynamics.

V. Adaptation and natural selection

- Adaptation: a feature of attribute that confers a survival or reproductive benefit (advantage) to its bearer; also the process by which this benefit is achieved; also the good fit between organism and environment.
- Parallels between adaptation and science as a way of knowing: Sterrer's idea of adaptation as hypothesis.
- Adaptation as a universal, expected condition in economic systems; organisms are continually tested and represent continuous lines of descent extending back to the origin(s) of life even in the face of challenges and disruptions.
- Reconciling the contradiction between evolutionary science (and adaptation) and religion: religion as social adaptation.
- Criteria for recognizing adaptation:
  Trait must be heritable (genetic or cultural)
  There must be identifiable agency of agent that links possession of the trait with a bearer's success in survival/reproduction
  The trait must be shown to have the function and effects that confer the purported benefit.

- Properties and scope of adaptation:

  The importance and universality of competition: all living things compete for locally limiting (scarce) resources.
  Adaptation is universal but imperfect: there is always room for improvement

Adaptation is sufficient, not optimal or the best that can be designed.
Adaptation as a process need not be continuous: the problem of stasis; the trade-off principle, costs and benefits.

- Conditions necessary for adaptation to occur: prolific and predictable resources, competition, a permissive environment in which errors and experimentation are tolerated.
- Measuring adaptation:

Energy: a means of exchange like money, a measure of capacity; measured as force (measured in newtons) times distance, in joules.
Power: a measure of effectiveness and performance, fitness, influence, productivity; measured as energy per unit time, in watts.
Efficiency: energy gained compared to energy expended or invested; not the same thing as effectiveness.

- Enemies vs. victims: adaptations of enemies often function to increase power; those of victims function to reduce enemies' power.
- Enabling factors and selective agencies:

Enabling factors make adaptation possible and set limits to it; are necessary but not sufficient for adaptation; examples: properties of the environment (temperature, density and viscosity of medium, ecosystem productivity, resource availability, the technology of form and physiology) the time-energy budget of an organism - the supply side of adaptation.

Selective agencies: competition in the broad sense (including predation, disease, parasitism), compelling organisms to adapt and setting performance standards - the demand side of adaptation.

Feedbacks between enabling factors and selective agencies.

- Enemies as ubiquitous and primary selective agents: enemies have more power than victims, affect and control the morphology, behavior and distribution of victims.
- Resources over which organisms compete: Food, nutrients, light, water, shelters, mates (in species with internal fertilization or territorial fertilization), status (in social species).

- Coevolution and escalation:
  Coevolution: reciprocal evolution between two parties
  Escalation: enemy-directed evolution; the life-dinner principle, top-down selection.
- How adaptation is achieved: reducing functional trade-offs; cooperation between species and individuals, including symbioses; organisms modifying or changing its environment in a way favorable to itself; assigning new roles to old genes; expanding the time-energy budget.
- Genetic vs. cultural-learning inheritance
- Limits to adaptation: adaptation cannot anticipate the future except insofar as the future resembles the past; insufficient genetic variation on which selection can act; too much variation, leading to chaos; some adaptive pathways inaccessible because of entrenched developmental-genetic constructional pattern; the stamp of history ("phylogenetic constraint"); insufficient resources or energy; unpredictable challenges.

VI. What evolves?

- Entities must exist long enough as "individuals" and exhibit enough variation on which selection can act.
- Entities must have the capacity to multiply (or reproduce, sexually or asexually) to be copied.
- How groups can become units of selection

VII. Emergence and the fundamental nature of interaction

- Interaction between entities is universal, from subatomic particles to galaxies
- Interactions cause structures and traits to emerge that the parties by themselves do not possess. Examples: books, sentences, words, chemical compounds, ecosystems, multicellular organisms, life itself; survival and reproduction and adaptation as emergent phenomena
- Purpose and meaning in human society as emergent phenomena of great importance
- Complexity as emergence

VIII. Reconstructing the history of life: phylogeny and the fossil record

- Evolution as a branching process: the metaphor of the tree of life
  Clade: an ancestor and all its descendants
  Lineage: a twig, unbranched tip on the tree of life
  Sister groups: clades coming from a single node in the tree
  Conserved and derived traits
  Divergence, convergence, parallel evolution, homology, parsimony
  Vertical vs. horizontal transmission in phylogeny
- Clade replacement over time
- The fossil record
  Brief overview of the geological time scale, historical highlights
  Nature and limitations of the fossil record
  Extinction: when adaptation fails
- Patterns in history
  Unregulated flexibility replaced by genetic control
  The origins of novelty, increase in adaptive versatility
  The role of escalation in expanding phenotypic space and surmounting evolutionary limitations over time
  The increasing interdependency among organisms over time, increased control by organisms over resources, climate and other aspects of the environment
  Contingency and directionality: the waning role of randomness
  Overview of some repeatedly evolved traits and capacities: endothermy, biomineralization, intelligence, leaves, trees, herbivory, transitions between land and sea, sociality, powered flight, etc.
  The formation of species through genetic isolation and patterns of increasing diversity over time

IX. Evolution in the human realm

- Language, culture, technology, religion, military escalation, antibiotics and disease, modifying other species, our morphological specializations; the historical record

X. Summation

- How not to use evolution: no survival of the fittest; not everything is adaptive; we cannot blame all our shortcomings on our Pleistocene past; we cannot invent just-so stories without evidence.

- Methodological issues

  It is important to observe selection in progress, not just to collect final results from experiments on selection.
  Important to distinguish causes from correlations
  Important to distinguish description from explanation; the latter implies mechanisms.
  Important always to pursue science ethically, cooperatively, and honestly

- Outstanding questions:

  How much horizontal gene transfer exists and will biotechnology seriously jeopardize the evolutionary process?
  How predictable is evolution and history in general?
  Which mechanisms account for species formation, and which of these are most important?
  Does selection work as discrete event or continuously?
  How often is mutation responsible for the variation on which selection acts?
  How do traits such as consciousness and intelligence arise?