Biology 582: From DNA to Diversity: The molecular basis for evolutionary change.

* Note – This syllabus is subject to change!

Course zoom links:

Instructor: <PROF_FULL_NAME>
Remote office hours: By appointment
Zoom link: <LINK_ZOOM>
Email: <PROF_EMAIL>

Graduate TA: <TA_FULL_NAME>
Remote office hours: Fridays 12-1pm
Zoom link: <LINK_ZOOM>
Or in person: Morrill South 336
Email: <TA_EMAIL>

Textbook

From DNA to Diversity: Molecular Genetics and the Evolution of Animal Design, 2nd edition (2005) – Carroll SB, Grenier JK, and Weatherbee SD. [Required chapters/sections will be posted on Moodle as PDFs]

Course Description

How does development influence evolution? This simple question has inspired evolutionary biologists since Darwin, who recognized that species-specific shapes often arise during embryogenesis. We can think of evolution as consisting of two steps: (1) the generation of organismic variation, and (2) the differential survival of variants within a population. The "Modern Synthesis" of the 1930s and 1940s united evolutionary biology and Mendelian genetics to explain the origin and maintenance of adaptive variation within populations/species. It's focus, in other words, was on step 2, or the "survival of the fittest." The Modern Synthesis could not, however, identify the specific genetic changes that underlie evolutionary change, nor could it account for major evolutionary transitions. Evolutionary developmental biology (aka: 'evo-devo') seeks to complement the Modern Synthesis by identifying the developmental genetic changes that underlie evolution. The emphasis of evo-devo is on step 1, or the "arrival of the fittest," and is grounded by the idea that changes in evolution are caused by heritable changes in development.

Evo-devo is motivated by questions that have been asked by biologists for hundreds of years: How does development produce complex structures (e.g., wings, fins, heads and flowers) from a single cell zygote? How has natural selection acted on the developmental program to produce adaptive phenotypic variation? What goes wrong in development when disease occurs? For centuries these basic questions have gone unanswered. Significant technological advances in genomics and developmental genetics (including gene/genome editing) now allow biologists to understand how genes control development, and how development drives (or limits!) evolution. Indeed, these advances are so significant, that it is now possible to contemplate altering the course of evolution (e.g., de-extinction). We will explore such topics and questions this semester.

Learning Goals

Knowledge Outcomes*:* On completing this course you should have a solid understanding of (a) evolutionary patterns and processes (e.g., homology at different levels of biological organization), (b) developmental logic,

(c) principals of gene regulation (e.g., enhancers and their role in development and evolution), and (d) the "rules" that permit and limit evolutionary change. In addition, you should be comfortable reading and processing the primary scientific literature, as well as distilling and communicating information gleaned from these sources.

In *On the Origin of Species*, Charles Darwin referred to "endless forms most beautiful" when describing the biodiversity that surrounds us. I want you to come away from this class, quite simply, with an appreciation for *how* these endless forms have come to be – e.g., how development makes a limb, how snakes lost their limbs, how the bat got its wing, etc.

Course Format

I. General

Each week's assigned readings will be available for download from Moodle the previous Friday, and lectures (.pptx) will be available for review the evening before class. ***Attendance is expected***. You will not be able to obtain all of the necessary information from the lecture slides or readings alone.

II. Quizzes

Many class meetings will begin with a short quiz that will cover that day's assigned readings. Quizzes will be i>clicker based and there will be 14 of them. Assigned readings should therefore be done before class! ***There will be no make-up quizzes***. Instead, I will drop your 4 lowest quiz grades. Thus, your final quiz grade will be based on 10 quizzes.

III. Exams

You will have three exams over the course of the semester. They ***will not be cumulative***. I will provide more information about these as they near.

IV. Creatively scientific writing

This is your final assignment where you will show off everything that you have learned over the semester: **Build me a hypothetical animal – a "hopeful monster".** Tell me where this animal lives and how it is adapted to its environment. Most importantly, you should be able to connect the dots from (**i**) genetic alterations/ mutations, (**ii**) through morphogenesis, (**iii**) to the production of the phenotype. While a creative exercise, you will be evaluated based on the science behind your "story". As such, this endeavor should be scientifically grounded and based on real processes (*use citations!*). Convince me that this *could* happen - e.g., you must be mindful of the rules of development and evolution. The paper should be no more than 5 pages (1.5 line spacing, excluding references or figures/illustrations).

We will dedicate time in the lab to discuss your papers and tips for how to select and research traits that you will endow your creature with (you need at least 3). You will also turn in an annotated bibliography (9+ references minimum — 3/trait) before the Thanksgiving break. I will provide critical feedback, and the exercise will contribute 5% of your total course grade.

V. Laboratory section

There will be a 1 credit (3 hour/week) laboratory section associated with this class. Herein we will explore the development and evolution of an important novelty – the vertebrate jaw. In particular, we will use the jaw as a paradigm in which to explore the concepts of "modularity" and "individualization" in the development and evolution of animal body plans. In the lab, you will be guided through a series of exercises that will expose you to the integrative nature of evo-devo, and allow you to gain practical experience in a wide range of techniques used in the field, from experimental embryology to statistical shape analyses. Most meetings will begin with a brief lecture, and/or review of the day's assigned reading, followed by a "hands on" exercise.

Broadly, the lab will be divided into 3 themes: Anatomy, Development and Evolution. Following an initial survey of skull diversity across vertebrates, we will explore the developmental origins and pattering of the jaw skeleton using a popular animal model – the zebrafish. The semester will end with an analysis of co-evolution of different skeletal elements across a particularly successful group of fishes — cichlids from East Africa. Details of your lab grade will be provided in lab.

Attendance Policies

Lecture – Formal attendance will not be taken; however, it will be important to attend all lectures to gain a full and comprehensive understanding of the material. Readings and posted lecture slides are intended to *supplement*, not replace, my lectures.

Lab – Formal attendance will note be taken; however, a significant proportion of your lab grade will be based on your lab notebook in which you will document the day's activities including methods, images, data, results and interpretations.

Grading

This course seeks to measure your abilities to absorb new concepts, while also focusing on your abilities to integrate and communicate what you have learned. Each component will be weighted as follows:

Quizzes:	(10 x 1%)	**10%** (contribution to final grade)
Exams:	(3 x 11%)	**33%** (contribution to final grade)
Paper:	(5% bibliography + 30% final)	**35%** (contribution to final grade)
Lab:		**22%** (contribution to final grade)
		100%

Grading scale

100-93	A
92.99-90	A-
89.99-88	B+
87.99-83	B
82.99-80	B-
79.99-78	C+
77.99-73	C
72.99-70	C-
69.99-68	D+
67.99-63	D
62.99-60	D-
Below 60	F

Course Schedule

WEEK 1: INTRO & OVERVIEW OF EVO-DEVO & A BRIEF HISTORY OF ANIMALS

September 6 – *Welcome & Introduction!*

September 8 – *Lecture*

1) *Carroll, et al. Chapter 1, pp. 1-15.*

No Lab - But read paper from DeLaurier, which will be a reference/guide for the semester!

***WEEK 2: ANIMAL ORIGINS &* THE GENETIC TOOLKIT FOR ANIMAL DEVELOPMENT**

September 13 – *Quiz 1; Lecture*

1) King N. 2004. The unicellular ancestry of animal development. *Dev Cell.* 7:313-25.

September 15 – *Lecture*

Lab 1 [room: Morrill 343] – Origins and Anatomy of the vertebrate jaw

WEEK 3: THE GENETIC TOOLKIT FOR ANIMAL DEVELOPMENT – HOMEOTIC MUTATIONS AND HOPEFUL MONSTERS.

September 20 – *Quiz 2; Lecture*

1) *Carroll, et al. Chapter 2, pp. 17-50; Carroll, et al. Chapter 3, pp. 55-59. (a brief review of gene logic).*

September 22 – *Quiz 3; Intro and Lecture*

1) Leroi AM. *Mutants: On Genetic Variation and the Human Body*. Chapter 2, pp. 23-62.
2) Leroi AM. *Mutants: On Genetic Variation and the Human Body*. Chapter 5, pp. 137-165.

Lab 2 [room: Morrill 343] – Form-function of the jaw

WEEK 4: EVOLUTION OF THE TOOLKIT

September 27 – *Quiz 4; Lecture*

1) Carroll, et al. Chapter 4, pp. 103-127.
2) Rohner et al., 2009. Duplication of *fgfr1* permits Fgf signaling to serve as a target for selection during domestication. *Current Biol.* 19:1-6.

September 29 – *Lecture wrap-up*

Lab 3 [room: Morrill 343] – Modularity and individualization of the jaw

WEEK 5: EXAM 1 &
DEVELOPMENT & DIVERSITY OF ANIMAL FORM – LESSONS FROM INSECT SEGMENTATION

October 4 – ***Exam 1 (covering material through Sept. 29)***

October 6 – *Lecture*

1) Carroll, et al. Chapter 3, pp. 61-81.
2) Carroll, et al. Chapter 5, pp. 131-140.

Lab 4 [ISB 360] – Neural crest cells and the development origins of the jaw

WEEK 6: DEVELOPMENT & DIVERSITY OF ANIMAL FORM – LESSONS FROM THE VERTEBRATE LIMB

October 11 – *Lecture*

October 13 – *Quiz 5; Lecture*

1) Carroll, et al. Chapter 3, pp. 87-95.
2) Onimaru K, et al., 2016. The fin-to-limb transition as the re-organization of a Turing pattern. *Nat Commun*. 7: 11582.

Lab 5 [ISB 360] – Mutations and jaw development

WEEK 7: WHAT IS A LIMB, ANYWAY? "LIMBS" IN FISHES & SQUID!

October 18 – *Quiz 6; Lecture*

1) Stewart TA, et al., 2020. Fin ray patterns at the fin-to-limb transition. *PNAS*. 117(3):1612-1620.
2) Nakamura T, et al., 2016. Digits and fin rays share common developmental histories. *Nature*. 537(7619): 225-228.

October 20 – *Quiz 7; Lecture*

1) Tarazona OA, Lopez DH, Slota LA, Cohn MJ. 2019. Evolution of limb development in cephalopod mollusks. *Elife*. e43828.

Lab 6 [ISB 360] – Mutations and jaw development continued

WEEK 8: LIMB LOSS - HOW THE SNAKE (AND WHALE) LOST ITS LEGS

October 25 – *Lecture only*

October 27 – *Quiz 8; Lecture*

1) Thewissen JG. 2006. Developmental basis for hind-limb loss in dolphins and origin of the cetacean body plan. *Proc Natl Acad Sci USA*. 103(22):8414-8.
2) Kvon EZ, et al., 2016. Progressive Loss of Function in a Limb Enhancer during Snake Evolution. *Cell*. 167(3):633-642.e11.

Lab 7 [Morrill 343] – Individualization of the pharyngeal skeleton across fishes: Constraints on evolution?

WEEK 9: EXAM 2 & HOW THE BAT GOTS ITS WING

November 1 – ***Exam 2 (covering material from Oct. 6-27)***

November 3 – *Lecture*

1) Sears KE, et al. 2006. Development of bat flight: morphologic and molecular evolution of bat wing digits. *Proc Natl Acad Sci USA*. 103: 6581-6.
2) Booker BM, et al., 2016. Bat Accelerated Regions Identify a Bat Forelimb Specific Enhancer in the HoxD Locus. PLoS Genet. 2016 Mar 28;12(3):e1005738.

Lab 8 [Morrill 343] – Individualization of the pharyngeal skeleton across fishes: Constraints on evolution?

WEEK 10: HOW THE TURTLE GOT ITS SHELL & WHY PIGEONS ARE COOLER THAN YOU THINK!

November 8 – *Quiz 9; Lecture*

1) Moustakas-Verho JE, et al. 2014. The origin and loss of periodic patterning in the turtle shell. *Development*. 141(15):3033-9.

November 10 – *Quiz 10; Lecture*

1) Shapiro MD, et al. 2013. Genomic diversity and evolution of the head crest in the rock pigeon. *Science*. 339(6123):1063-7.
2) Domyan ET, et al. 2016. Molecular shifts in limb identity underlie development of feathered feet in two domestic avian species. *Elife*. 5:e12115.

Lab 9 [Morrill 343] – Wrap-up data collection & Overview of data analysis and visualization

WEEK 11: EVOLUTIONARY MUTANT MODELS

November 15 – *Quiz 11; Lecture*

1) Albertson et al., 2009. Evolutionary mutant models for human disease. *Trends Genet*. 25(2):74-81.

November 17 – *Quiz 12; Lecture*

1) Riddle et al., 2018. Insulin resistance in cavefish as an adaptation to a nutrient-limited environment. *Nature*. 555(7698):647-651.

Lab 10 [Morrill 343] – Discussion of class papers – Choosing your traits & navigating the primary literature

WEEK 12: NO CLASS - ENJOY THE BREAK!!

No Lab

WEEK 13: PIGMENTATION & DOGS

November 29 – *Quiz 13; Lecture*

1) Manceau M, et al. 2010. Convergence in pigmentation at multiple levels: mutations, genes and function. *Philos Trans R Soc Lond B Biol Sci*. 365(1552):2439-50.

December 1 – *Quiz 14; Lecture – Domesticated dog*

1) Ostrander EA, et al. 2017. Demographic history, selection and functional diversity of the canine genome. *Nat Rev Genet*. 18(12):705-720.
2) Plassais J, et al. 2022. Natural and human-driven selection of a single non-coding body size variant in ancient and modern canids. *Curr Biol*. 32(4):889-897.

December 2 – *[Friday by 5pm] Turn in your annotated bibliography for your paper!*

Lab 11 [Morrill 343] – Final overview of data analysis and visualization

WEEK 14: EVO-DEVO and BEING HUMAN, EXAM 3, LAB NOTEBOOKS DUE!

December 6 – *Lecture*

1) Huerta-Sánchez E, et al., 2014. Altitude adaptation in Tibetans caused by introgression of Denisovan-like DNA. *Nature*. 512(7513):194-7.

December 8 – ***Exam 3 (covering material from Nov. 3 - Dec. 6)***

No Lab – Turn in lab notebooks by 5pm on Dec. 9th.

WEEK 16: FINAL PAPERS DUE!!

December 18 – *Final papers due on Sunday Dec. 18th, by 11:59pm.*

* Note – Lecture schedules/topics may change; check the Moodle website for updates.

Academic Honesty

It is expected that all work will be completed *individually* unless specifically instructed otherwise (as in a group assignment). For the final paper, you are welcome to discuss your ideas and references with each other, but each of you must write your own paper without assistance. ***Please see me***, if you have any questions about what constitutes plagiarism, or the proper use and crediting of primary literature. Violations of the academic honesty policy will be reported to the Academic Honesty Office, and result in a zero grade for the assignment.

Beyond plagiarism, quoting published material should be kept to a minimum, ***ideally never***. I am not interested in what others have to say on a topic, but rather what you have to say. Excessive quoting will lead to the loss of points (and generally put me in a bad mood).

Your final paper will be submitted via Turnitin. Submitted assignments will be included in the UMass Amherst dedicated database of assignments at Turnitin, and will be used solely for the purpose of checking for possible plagiarism during the grading process during this term and in the future.

Accommodation Policy

I am committed to providing equal educational opportunities and fair assessments for all students, and will work with Disability Services and students to arrange appropriate accommodations for student needs. ***My ability to do this depends on being informed of student needs as soon as possible***, ideally within the first 2 weeks of the semester. It is the student's responsibility to inform instructors of their needs with sufficient time for accommodations to be arranged.