EVO ED

INTEGRATING CONCEPTS ACROSS BIOLOGY'S SUB-DISCIPLINES

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Abstract

Students are often taught evolution in the context of ecological systems, isolated from genetic and cellular mechanisms. In reality, a complete understanding of evolution requires knowledge spanning many biological sub-disciplines. To address this issue, we developed case studies that track the evolution of traits from the genetic level, to protein function, cell biology and macroecology. These case studies help students examine the evolution of: (i) light fur in beach mice, (ii) seed shape and taste in peas; (iii) color vision in primates and (iv) toxin resistance in soft-shell clams. The cases were piloted in an introductory biology course at Michigan State University in the spring of 2012. Students who learned evolution in a case-study context were more able to (i) explain the molecular basis of mutation, (ii) describe how mutations lead to phenotypic change and (iii) make mechanistic links between genotypes and phenotypes. Case studies can be implemented within a course, within a course sequence or across the entire biology curriculum and are freely available for adaptation and use.

Introduction

The primary objective of this project is to develop and implement case studies that integrate evolutionary concepts from the molecular to the population level. This is a unique approach because it focuses on single study systems, in the context of case studies, with the evolutionary process traced from its origination in a DNA mutation, to the production of different proteins, to the fixation of alternate macroscopic phenotypes in reproductively isolated populations. This is a radical departure from most, if not all, curricular materials in evolution education, which typically focus on one or a few aspects of the biology of a study system that are involved in the evolutionary process. A truly integrated framework for understanding evolution is rarely provided. We are addressing this gap in understanding through the development and implementation of case studies that explicitly link molecular and cellular processes to evolution by natural selection.

Case Study Implementation

PHASE 1: SPRING 2012
LB 145 – Introductory Cell and Molecular Bio (CASE STUDIES IMPLEMENTATION)
Students have previously taken an introductory organismal bio course.
LB144 – Introductory Organismal Bio (CONTROL)
Students have not previously taken a university-level bio course.
BS162 – Organisms and Populations (CONTROL)
Students have previously taken an introductory cell and molecular bio course.

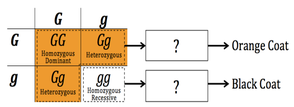
PHASE 2 will beginning in the Fall of 2012 where the cases will be used in additional courses.

Case Study Assessment

We used an open-ended assessment tool to evaluate student knowledge of evolutionary concepts at the beginning and at the end of the semester. It was designed to measure student ability to apply evolutionary principles in ecology (natural selection), genetics (mutation) and cell biology (the role of proteins). Validation of the assessment was done with student interviews.

Q1. Jaguars can have an orange coat or a black coat. Orange jaguars have either two *G* alleles or one *G* allele and one *g* allele, whereas black jaguars have two *g* alleles.

When a jaguar has the genotype *gg*, what happens so that a black coat is produced?



Q2. Toxican mushrooms contain a toxin that causes vomiting when ingested. Recently, some Toxican mushrooms were found that did not produce the toxin.

Describe in detail what might have happened **at the molecular level** so that these mushrooms no longer produce this toxin?

Q3. The non-poisonous Toxican mushroom has become more frequent in mushroom populations and poisonous Toxican mushrooms have become rare.

Define Natural Selection and use it to explain this scenario.

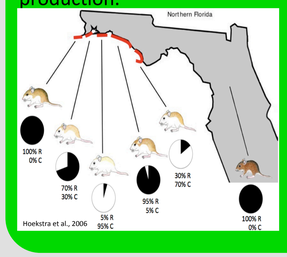
Q4. Considering genetic mutation –
(i) Describe, at the molecular level, what a mutation is.
(ii) Use your answer from part (i) to describe the **process** whereby a mutation results in a change at the phenotype level.

Case Study 1: Mouse Fur Color Evolution

Natural History: There are several sub-species of *Peromyscus* Beach Mice that live in the southeastern USA. Sub-species along coastal sand beaches tend to have light fur whereas inland populations tend to have dark brown fur.

Genetics: Sub-species that have light coats often have a mutation in their melanocortin 1 receptor (mc1r) gene on chromosome #16. This mutation is a single substitution at nucleotide #199 (of 954 nt) where a *cytosine* changed to a *thymine*. The result of this mutation is an amino acid change from arginine to cysteine in the resulting MC1R protein.

Cell Biology: The MC1R protein is a transmembrane protein. When MC1R binds to a melanocyte stimulating hormone is starts a multistep biosynthetic process that results in the production of the pigment eumelanin. The C→T mutation changes the MC1R protein structure, which inhibits it from effectively binding α-MSH, ultimately inhibiting effective eumelanin production.



Ecology: Evidence suggests that fur-environment color matching is as a result of selective predation from predators that can detect dark colored prey in a light background and vice-versa.

Population Genetics: Scoring genotypes and phenotypes of individuals from different populations show a strong link between the presence of the mutated MC1R allele and light fur.

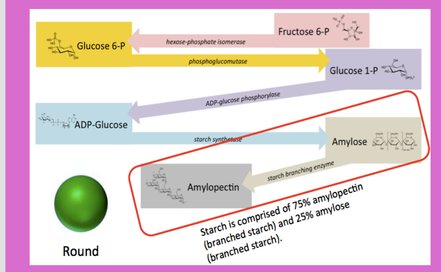
Key References:
(1) Barsh (1996) *Trends in Genetics*, 12 (8): 299-305. **(2)** Hoekstra *et al.* (2006) *Science*, 313: 101-104.
(3) Kaufman (1974) *Journal of Mammalogy*, 55(2): 271-283.

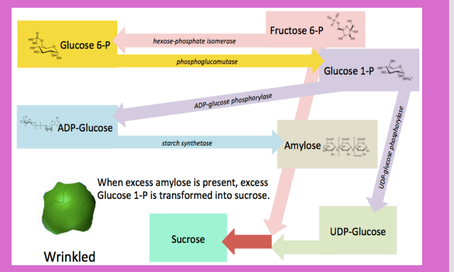
Case Study 2: Pea Seed Shape and Taste Evolution

Natural History: Field peas have been grown and eaten by humans for more than 12,000 years. Ancient pea populations were starchy and round; modern pea populations are wrinkled and sweet.

Cell Biology: When pea plants have a functional starch-branching enzyme (SBE) they can convert sugar into starch. Without a functional SBE, less starch is made and excess sugars are converted into sucrose. Peas with high sugar content retain water and dry out to become wrinkly.

Genetics: A functional SBE is coded for by the *R* allele of the sbe1 gene. A non-functional SBE is coded for by the *r* allele of the sbe1 gene. These alleles are identical with the exception of an 800bp insertion into the *r* allele sequence. This insertion makes the SBE protein non-functional.





Ecology and Population Genetics: Selective crop breeding of a homozygous recessive trait can be very effective and dominant alleles can be removed from populations in a matter of generations. In the case of round and wrinkled peas, humans have provided the (artificial) selection agent that has resulted in *r* allele fixation in domestic pea populations.

Key References:
(1) Bhattacharyya *et al.* (1990) *Cell*, 60: 115-122. **(2)** Guilfoile (1997) *American Biology Teacher*, 59(2): 92-95. **(3)** Ljustina and Mikic (2010) *Field and Vegetable Crops Research*, 47: 457-460.

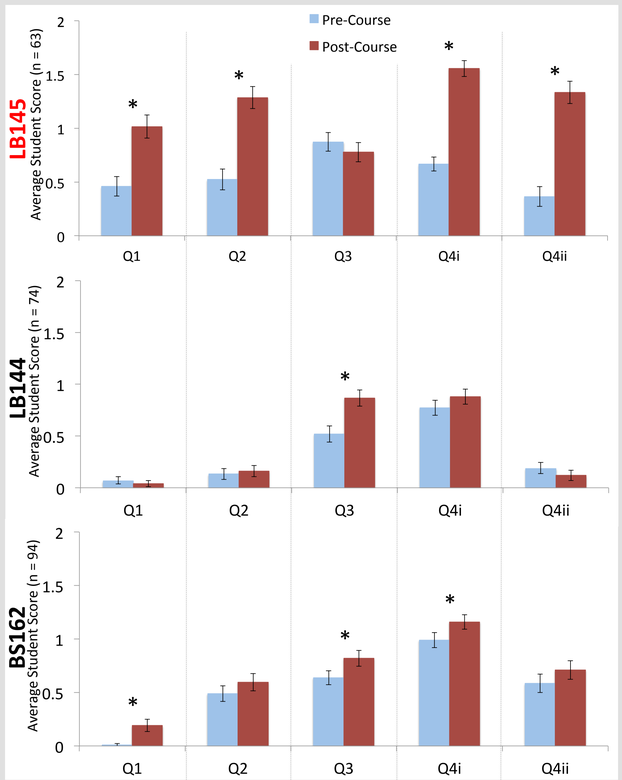
Case Study 3: Toxin Resistance in Clams

Case Study 3: Toxin Resistance in Clams A single nucleotide substitution mutation in a voltage gated sodium channel gene makes soft shell clams resistant to paralytic shellfish poisoning. Clams without the mutation are unable to transmit action potential down neuron axons.

Case Study 4: Trichromatic Vision in Primates

Case Study 4: Trichromatic Vision in Primates The long wave sensitive opsin gene originated from the duplication and mutation of the medium wave sensitive opsin gene, around 40 MYA. Trichromatic vision makes primates more efficient foragers in fruit trees.

Results



Questions were scored on a 2-point scale:
0 = response is absent, incorrect or mostly incorrect
1 = response is partially correct
2 = response is correct or mostly correct

Students who learned evolution through a molecular and genetic foundation (**LB145**) had a more complete understanding of evolutionary mechanisms than students who learned evolution in the traditional way, from an organismal perspective.

Discussion

Preliminary research suggests that an integrative case study approach to evolution education is effective for helping students learn the mechanisms of evolution. Successful case study implementation will require students to have a very basic understanding of genetic and molecular concepts. This understanding often comes as a natural progression of learning in introductory cell and molecular courses but curriculum adjustment may be required to help students understand these concepts in introductory organismal courses.

Additional data collection is scheduled for the fall of 2012 to verify our pilot study results.

Acknowledgements

This project is funded by NSF and by Lyman Briggs College at Michigan State University. Thanks to Kathis Ellis and Joe Murray for their administrative assistance. The website was created with the technical expertise of Miles Loh. We would also like to thank the following Lyman Briggs and MSU faculty for their involvement in our project: Kendra Cheruvelil, Gerry Urquhart, Chuck Elzinga, Cherryl Murphy and Alex Shingleton.