# Integrative Case Studies in Evolution Education

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## Abstract

Students are often taught evolution in the context of ecological systems and isolated from genetic and cellular ones. 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 molecular genetic level, to protein function, cell biology and macroecology. These case studies help students examine the evolution of: (i) light fur in beach mice (*Peromyscus polionotus*); (ii) trichromatic vision in old world primates; (iii) seed shape and taste in peas (*Pisum sativum*); and (iv) toxin resistance in soft-shell clams (*Mya arenaria* – in process). The cases were implemented into introductory biology courses at Michigan State University in the spring of 2012. To test the effectiveness of this integrative approach to evolution education, we developed and validated an assessment tool that was employed using a pre-post test design. Data analysis from spring 2012 is currently underway. Case studies can be implemented within a course, within a course sequence or across the entire biology curriculum and are freely available for use.

## Introduction and Methods

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.

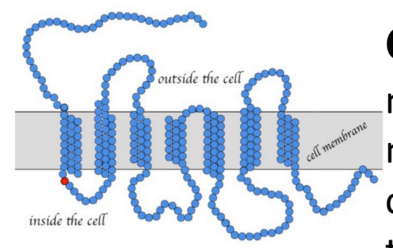
In this work we advance the hypothesis that students who develop an elementary understanding of evolutionary processes more broadly, but particularly on a cellular and molecular level, develop a better overall understanding of evolution. Most introductory teaching of evolutionary principles that our students experience tends to be somewhat superficial, mainly because the principles of evolutionary theory are typically taught before our students have gained a meaningful understanding of cellular and molecular biological processes. Thus, the learning of evolution is predominantly achieved through the guises of phenotypic variation and natural selection whereas a complete understanding requires an integration of knowledge from across biological sub-disciplines. We are addressing this gap in understanding through the development and implementation of case studies that explicitly link molecular and cellular processes to natural selection. The case study approach allows students to engage and explore carefully chosen scenarios that: 1) guide them to basic content understanding; 2) engage them in scientific debates; 3) make them choose between alternative hypotheses; 4) provide practice applying knowledge; and 5) teach the skill of verifying information.

There are two levels of implementation for our case studies: in-class and online. In-class implementation was facilitated by creating PowerPoint slides and teaching notes for distribution to course instructors. Four MSU undergraduate courses (LB144, LB145, BS162, and ZOL445) were involved in pilot tests of the case studies during the Fall 2011 and Spring 2012 semesters. Each course instructor determined how case studies would be best integrated into the existing curriculum of their individual course. Online implementation is currently underway through the creation of a website that presents the case studies and encourages user interaction through game-style apps.

We used an open-ended assessment tool to evaluate student knowledge of evolution concepts at the beginning (pre-course) and at the end (post-course) of the semester. The assessment tool was validated by interviewing students from the targeted courses. Evaluation of assessment tool data is currently in progress.

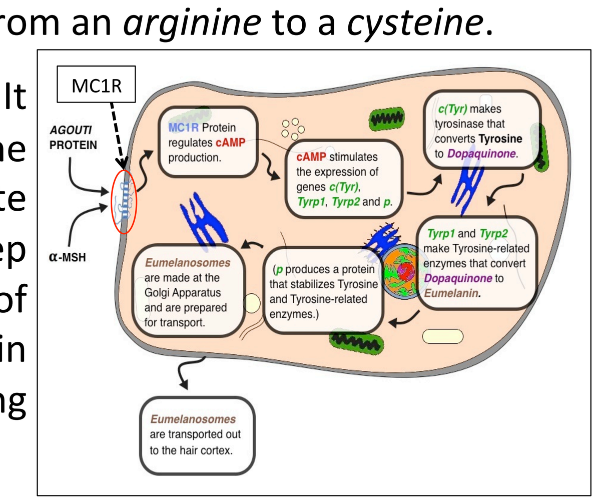
## Case 1 – Light Fur Color Beach Mice

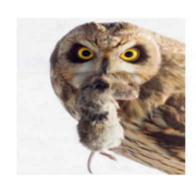
**Natural History**: There are several sub-species of *Peromyscus* Beach Mice that live in the southeastern USA. Sub-species along coastal sand beaches tend to have light fur whereas inland populations tend to have dark brown fur.




**Genetics**: Sub-species that have light coats often have a mutation in their melanocortin 1 receptor gene on chromosome #16. This mutation is a single nucleotide substitution at base-pair #199 (of 954 bp) where a *cytosine* changed to a *thymine*. The result of this mutation is an amino acid change in the resulting MC1R protein at position #67 from an *arginine* to a *cysteine*.

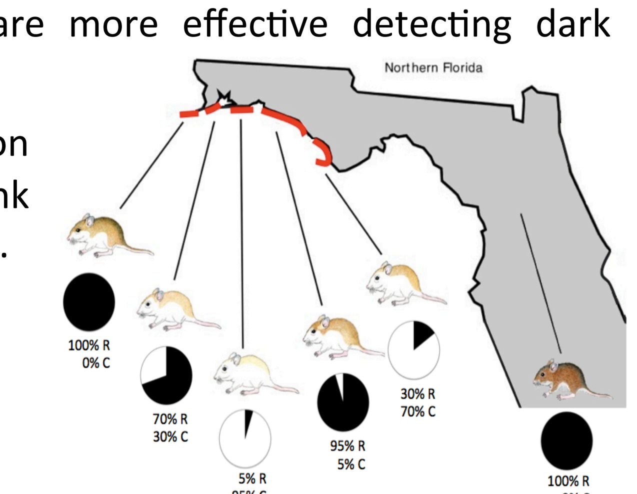
**Cell Biology**: The MC1R protein is a trans-membrane protein. It binds to a melanocyte stimulating hormone (α-MSH) and the *agouti* protein and regulates cyclic adenosine monophosphate production (cAMP) within the cell. cAMP is required in the first step of a complex intracellular process that results in the production of the pigment eumelanin. The C→T mutation leads to a change in MC1R protein structure, which inhibits it from effectively binding α-MSH, ultimately inhibiting effective eumelanin production.



**Ecology**: Evidence suggests that fur-environment color matching occurs as a result of selective predation from visual predators that are more effective detecting dark colored prey in a light background and vice-versa.

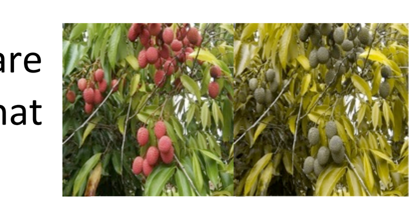
**Population Genetics**: Genotype-phenotype determination of individuals from different populations show a strong link between the presence of the mutated MC1R allele and light fur.




**Key References**:

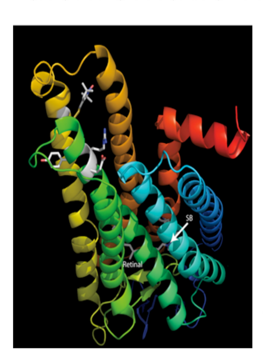
Barsh, G.S. (1996) *Trends in Genetics*, 12 (8): 299-305.
Hoekstra, H.E. *et al.* (2006) *Science*, 313: 101-104.
Kaufman, D.W. (1974) *Journal of Mammalogy*, 55(2): 271-283.

## Case 2 – Opsin Evolution Primates



**Natural History**: Primate species that live in the Old World (OWPs) are trichromatic, that is they can see a full spectrum of color. Primate species that live in the New World (NWPs) are dichromatic, that is they are colorblind.

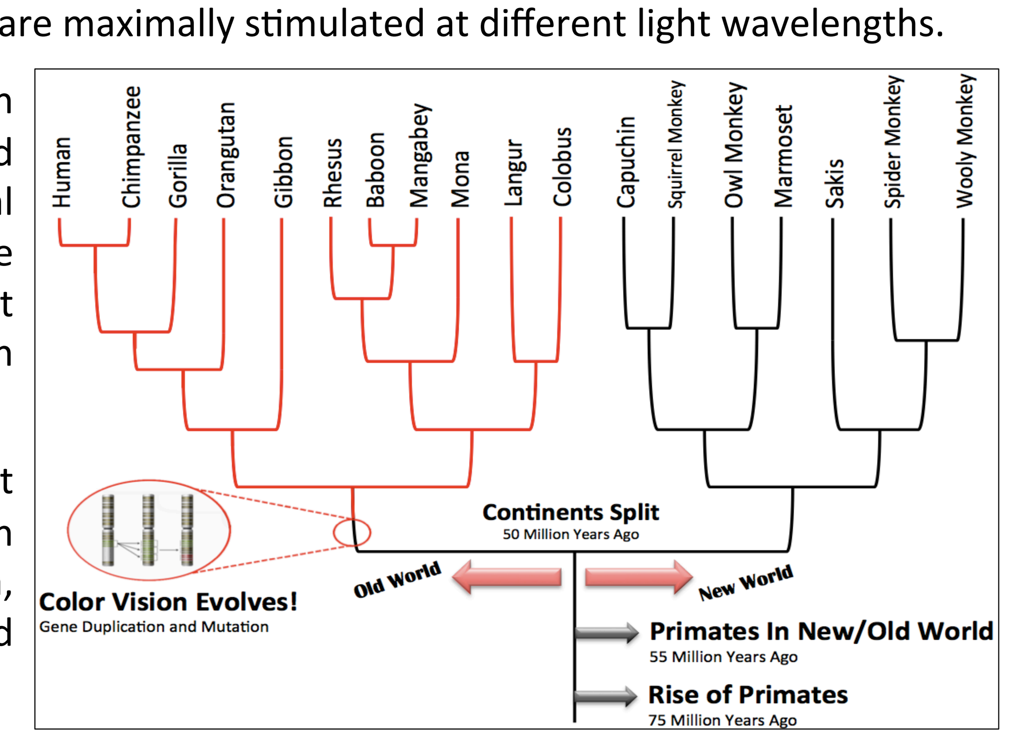
**Ecology**: Trichromatic vision allows for optimal food-foraging in the day; dichromatic vision allows for optimal food foraging in low-light conditions.



**Cell Biology**: Color vision is facilitated by transmembrane opsin proteins in cone cells located in the retina of the eye. OWPs have three opsin proteins (long wave sensitive, LWS; medium wave sensitive, MWS; short wave sensitive, SWS) whereas NWPs only have two (LWS and MWS). When an opsin protein is stimulated by a photon of light it sends a signal to the brain that light has been detected. Each of the three types of opsin protein are maximally stimulated at different light wavelengths.

**Genetics**: The LWS and MWS opsin genes are adjacent to one another, located on the X- chromosome. They are identical in length (1092 bp) and differ in sequence by only 3 nucleotides. This indicates that the LWS opsin gene arose by duplication and mutation of the MWS opsin gene.

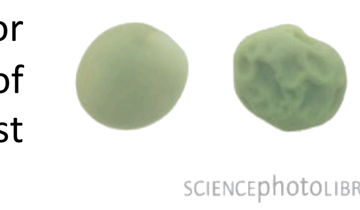
**Phylogenetics**: Analyses suggest that the LWS opsin gene likely evolved once, in an OWP common ancestor, ca. 50 mya, after the New World and Old World became distinctive land masses.




**Key References**:

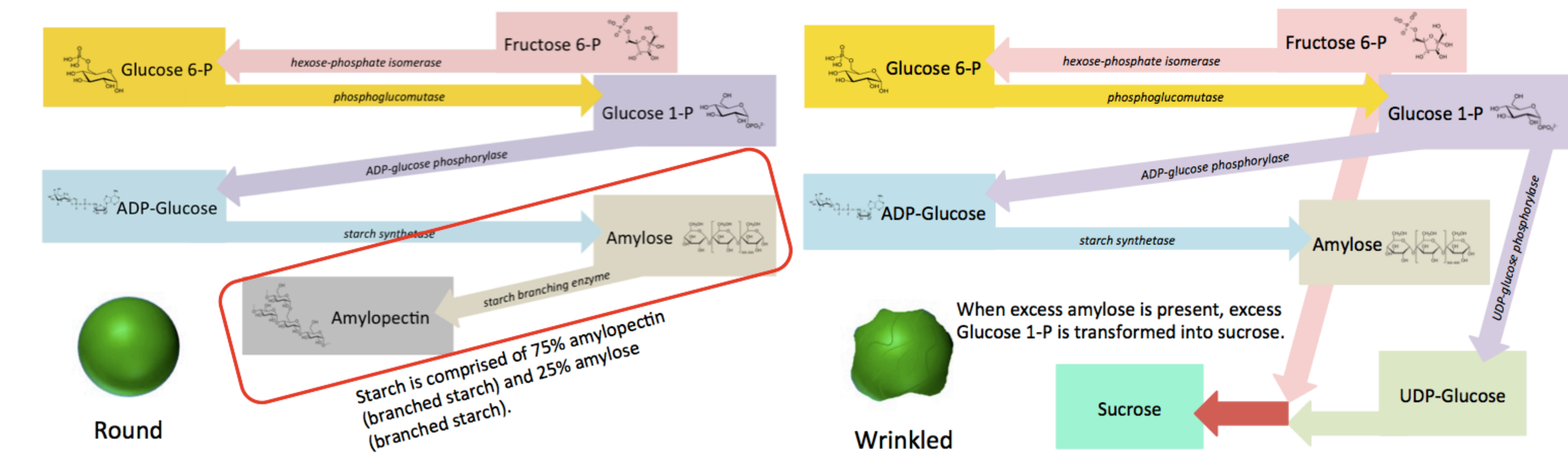
Caine, N.G. *et al* (2003) *International Journal of Primatology*, 24 (6): 1163-1175.
Dulai, K.S. *et al.* (1999) *Genome Research*, 9: 629-638.
Yokoyama, S. (2002) *Gene*, 300: 69-78.

## Case 3 – Pea Seed Shape and Taste

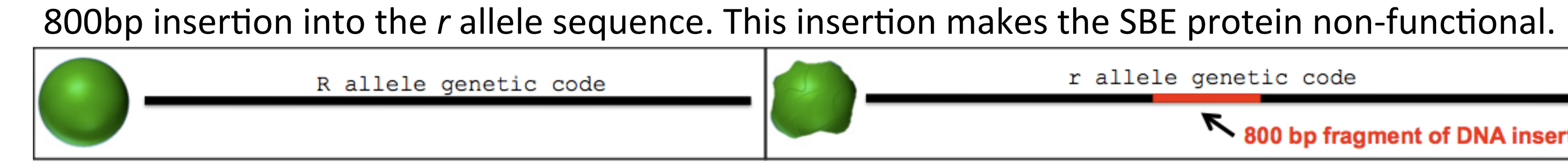



**Natural History**: Field peas have been grown and eaten by humans for more than 12,000 years. However, ancient pea populations consisted of round seeds with a starchy taste whereas modern pea populations consist of wrinkled peas with a sweet taste.

**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**:

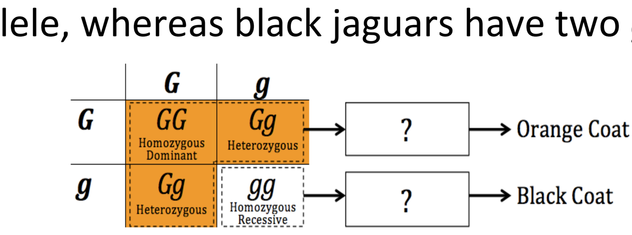
Bhattacharyya, M.K. *et al.* (1990) *Cell*, 60: 115-122.
Guilfoile, P. (1997) *The American Biology Teacher*, 59(2): 92-95.
Ljustina, M. and Mikic, A. (2010) *Field and Vegetable Crops Research*, 47: 457-460.

## Assessment of Case Studies

Case studies are being evaluated using an assessment tool that is administered at the beginning and at the end of our target courses. The assessment tool evaluates student ability to apply evolutionary principles in ecology (natural selection), genetics (mutation) and cell biology (the role of proteins). Our first round of data is currently being analyzed from the Spring '12 semester.

### Assessment Tool

Q 1. 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?

Q 2. 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.