The Integrative Approach to Evolution Education

EVOLVED

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NSF

MICHIGAN STATE UNIVERSITY

What is Evolution?

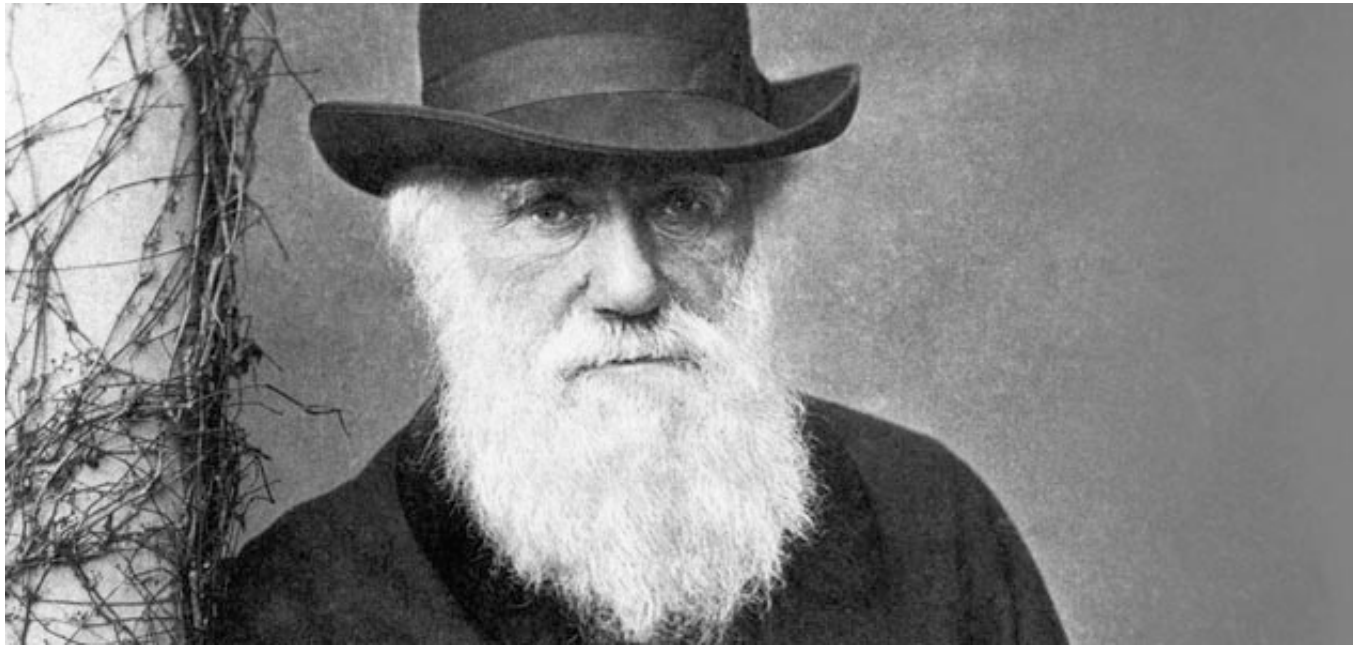
- Talk to your neighbor and come up with two things you can tell me about the biological theory of evolution.

How might a biology/science student explain the theory of evolution?

Evolution = Natural Selection

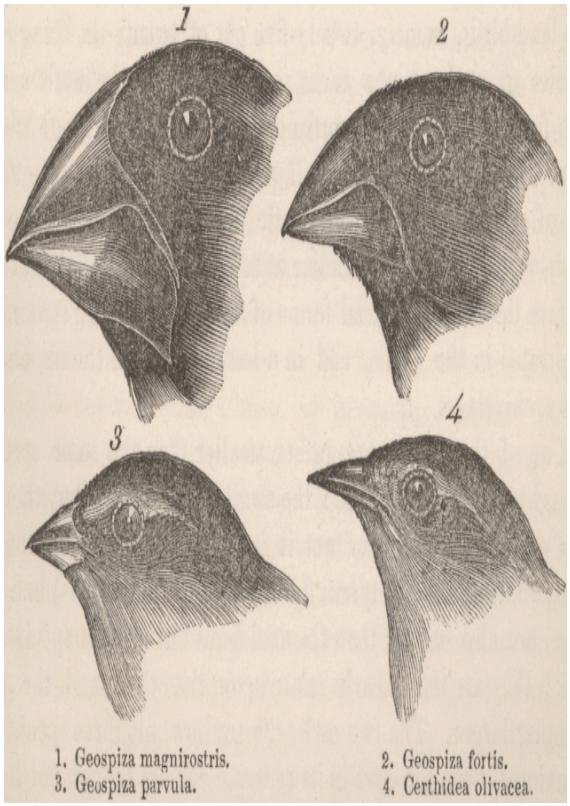
Darwin's Evolution

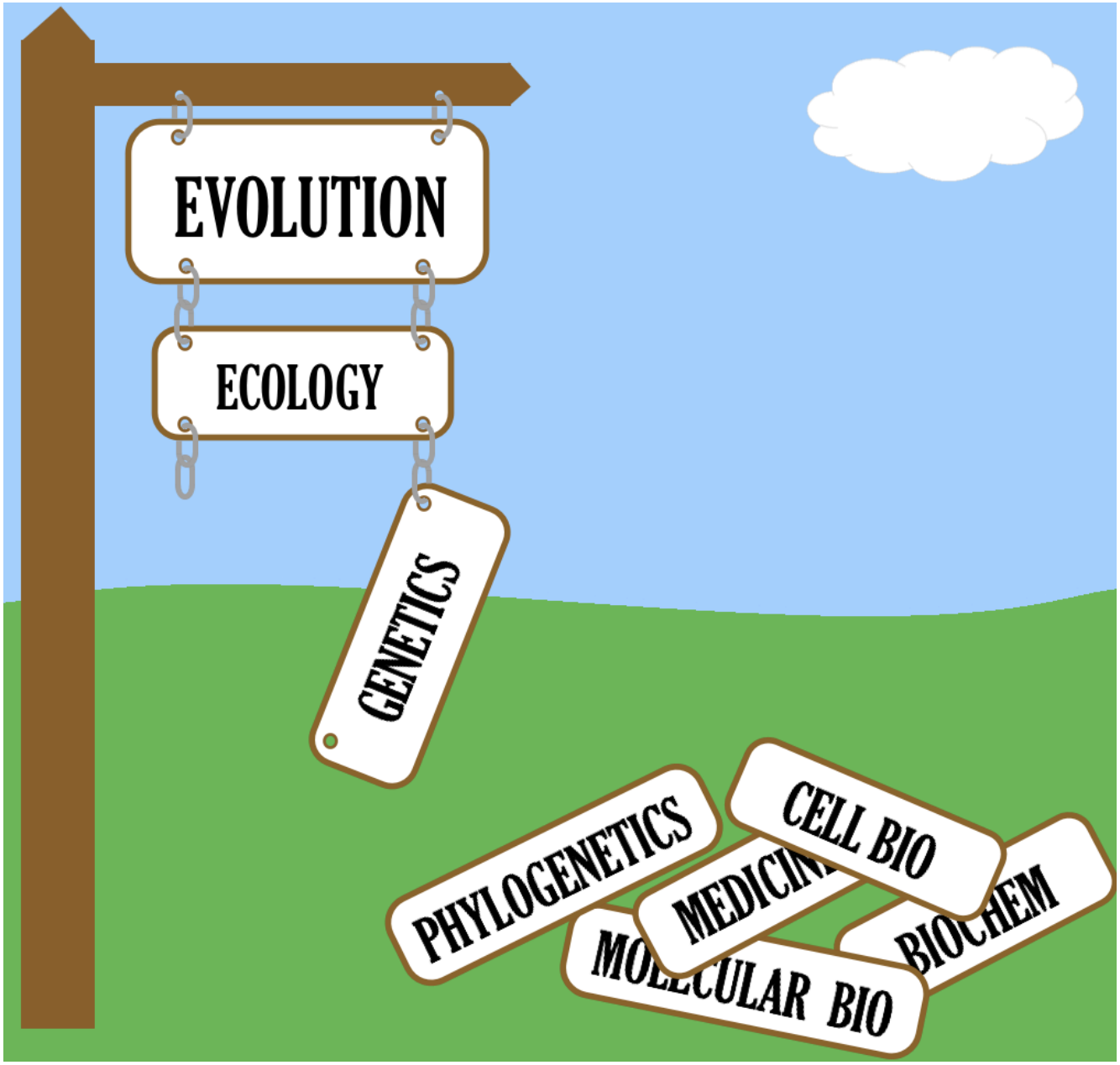
- Had no knowledge of genetics.
- Connected evolution with ecology.



Ecology and Evolution

- Beak size in Galapagos Finches




EVOLUTION
ECOLOGY
GENETICS
PHYLOGENETICS
CELL BIO
MEDICIN
BIOCHEM
MOLECULAR BIO

How would we like biology/science students to explain the theory of evolution?

Word cloud of the *Aims and Scope* of journals that have "Evolution" in their title

Evolution is cross-disciplinary.

Oftentimes, students complete their biology education without fully understanding how well supported the theory of evolution is.

Traditional undergraduate instruction does not necessarily help students understand evolution.

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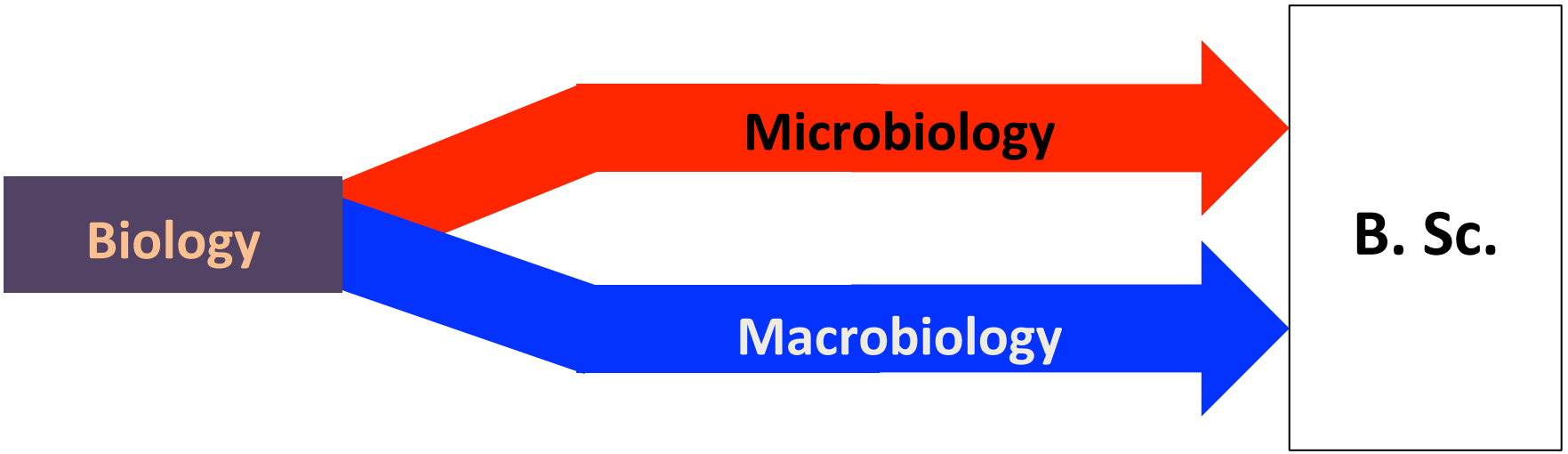

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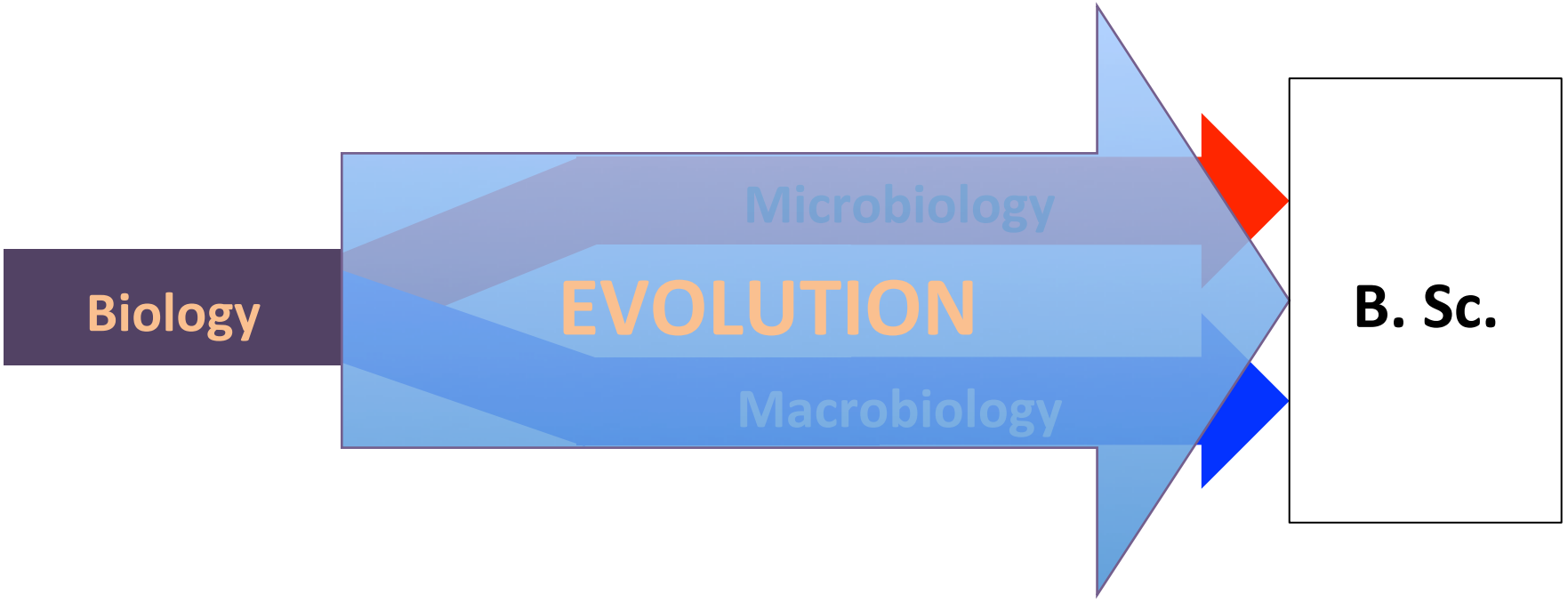


EVOLVED

Goals:

- Help students understand evolution as an integrative biological theory that spans across biological sub-disciplines.

- Provide curricular resources for biology instructors so they can teach evolution as an integrative biological theory.

EVO ED

Trichromatic Vision Evolution in Primates

Fur Color Evolution in Beach Mice

Seed Taste Evolution in Field Peas

Toxin Resistance Evolution in Clams

www.evo-ed.com

Evo-Ed: Case Studies for Effective Evolution Education

www.evo-ed.com

Reader

Lyman Briggs Apps | LB145 S13 Homepage | LB492 S13 Homepage | MSU Netfiles | Evo-Ed: Cas...n Education

EVO ED

Cases for Evolution Education

Monkey Opsins | Mouse Fur Color | Pea Taste | Clam Toxin | Games and Sims

A complete understanding of evolution requires knowledge that spans many biological sub-disciplines. However, students are often taught evolution in the context of ecological systems and isolated from genetic and cellular ones. To address this issue, we have developed case studies that track the evolution of traits from their origination in DNA mutation, to the production of different proteins, to the fixation of alternate macroscopic phenotypes in reproductively isolated populations.

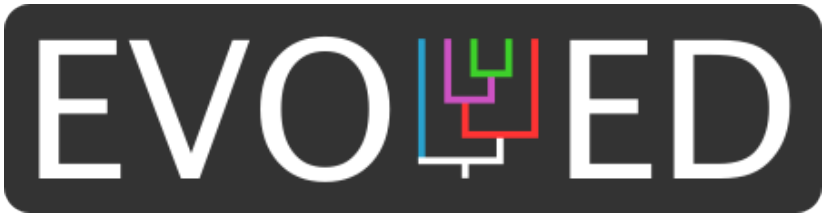
You can navigate through the case studies using the menu at the top of the page.

A short abstract of each case study is provided below with links to PowerPoint slides that are designed to be teaching resources for those who wish to implement one or more studies into their teaching.

"What does a Case look like?"

www.evo-ed.com

The Case of Color Vision Evolution in Monkeys



http://www.evo-ed.com

What is Evolution?

- Talk to your neighbor and come up with two things you can tell me about evolution.

What is Evolution?

A. Descent with modification.
B. The change of allele frequency within a population over time.
C. The process by which different species diversified from earlier forms during earth's history.
D. Natural selection of advantageous traits.
E. Genetic mutation that results in an altered phenotype.

On to color vision evolution in monkeys…

What is colorblindness?

Reduced ability to interpret light as color.

1 in 12 males are colorblind.

< 1 in 100 females are colorblind.

Are You Colorblind?

A) No (Female) 

B) Yes (Female) 

C) No (Male) 

D) Yes, very (Male) 

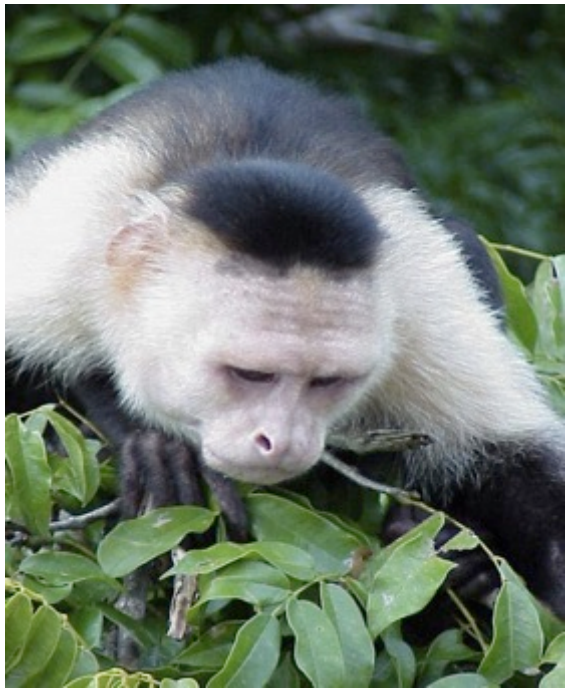
E) Yes, somewhat (Male) 

Color Vision in Monkeys

Species: Grey Cheeked Mangabey

Lives: Africa

Vision: Trichromatic vision (i.e. like most humans)



Species: White Headed Capuchin

Lives: Central and South America

Vision: Dichromatic vision (i.e. “colorblind”.

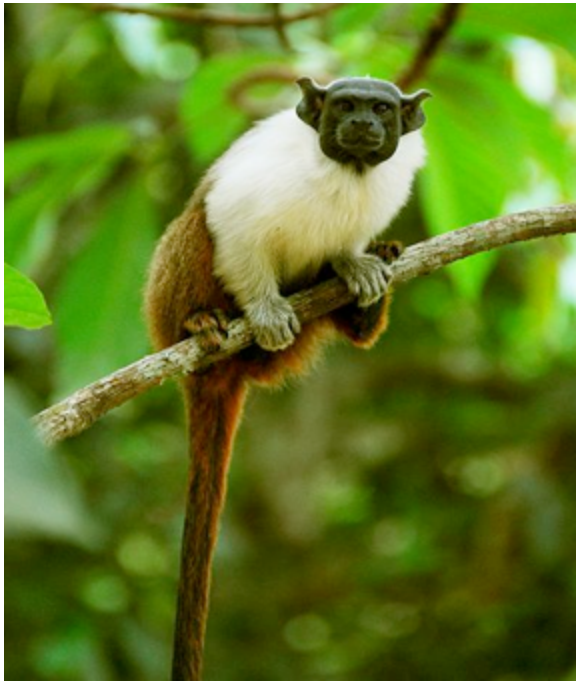
Color Vision in Monkeys

Species: Japanese Macaque
Lives: Asia
Vision: Trichromatic vision

Species: Black Squirrel Monkey
Lives: Central and South America
Vision: Dichromatic vision

Color Vision in Monkeys

Species: Roloway Monkey
Lives: Africa
Vision: Trichromatic vision



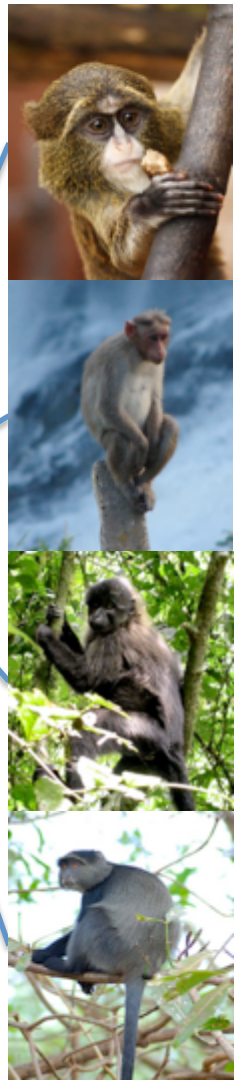
Species: Pied Tamarin
Lives: Central and South America
Vision: Dichromatic vision

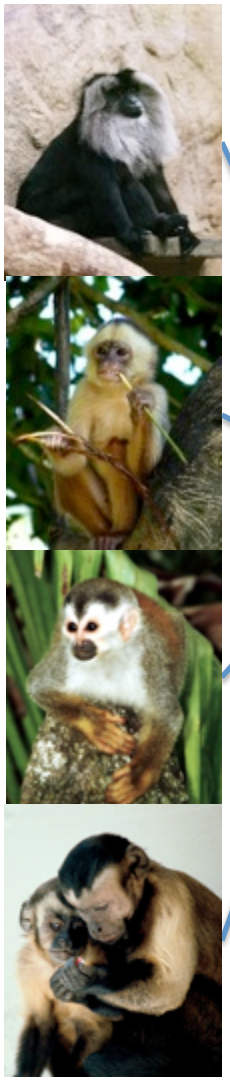
What have you noticed?

Monkeys of the World

TRICHROMATS

OLD WORLD





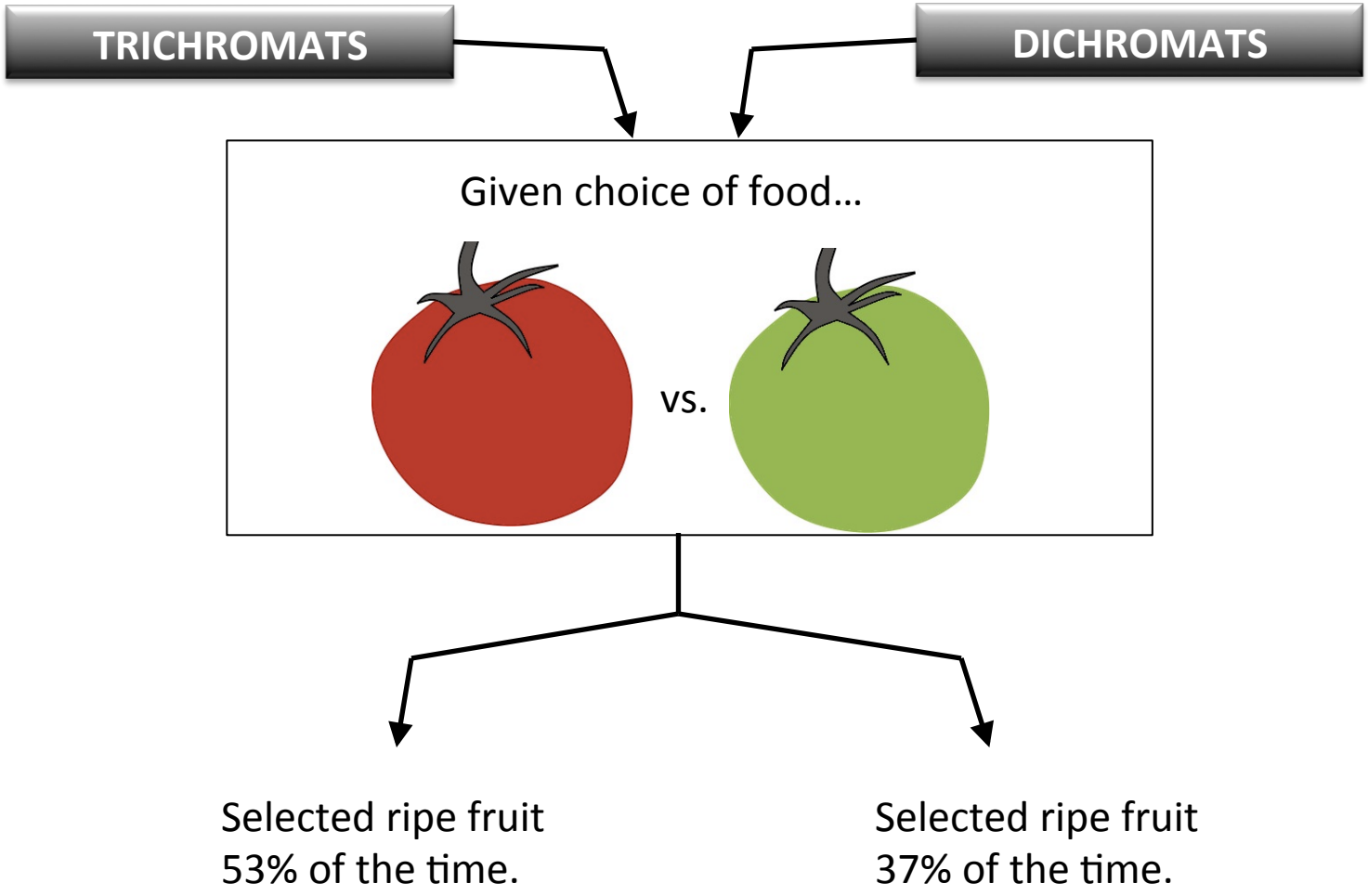
DICHROMATS

NEW WORLD

Ecology…

Food Selection –
The Driver of Trichromacy Evolution?

Food Selection – The Research Part I



$F_{1,10} = 8$, $p < 0.05$, Smith et al., 2003

Which peaches are ripe?

A) A
B) B
C) Both A and B
D) Neither A nor B
E) I can't tell

A

B

Which peaches are ripe?

A) A
B) B
C) Both A and B
D) Neither A nor B
E) I can't tell

A

B

If you were in a food-foraging competition, would having color vision give you an advantage over someone who was colorblind?

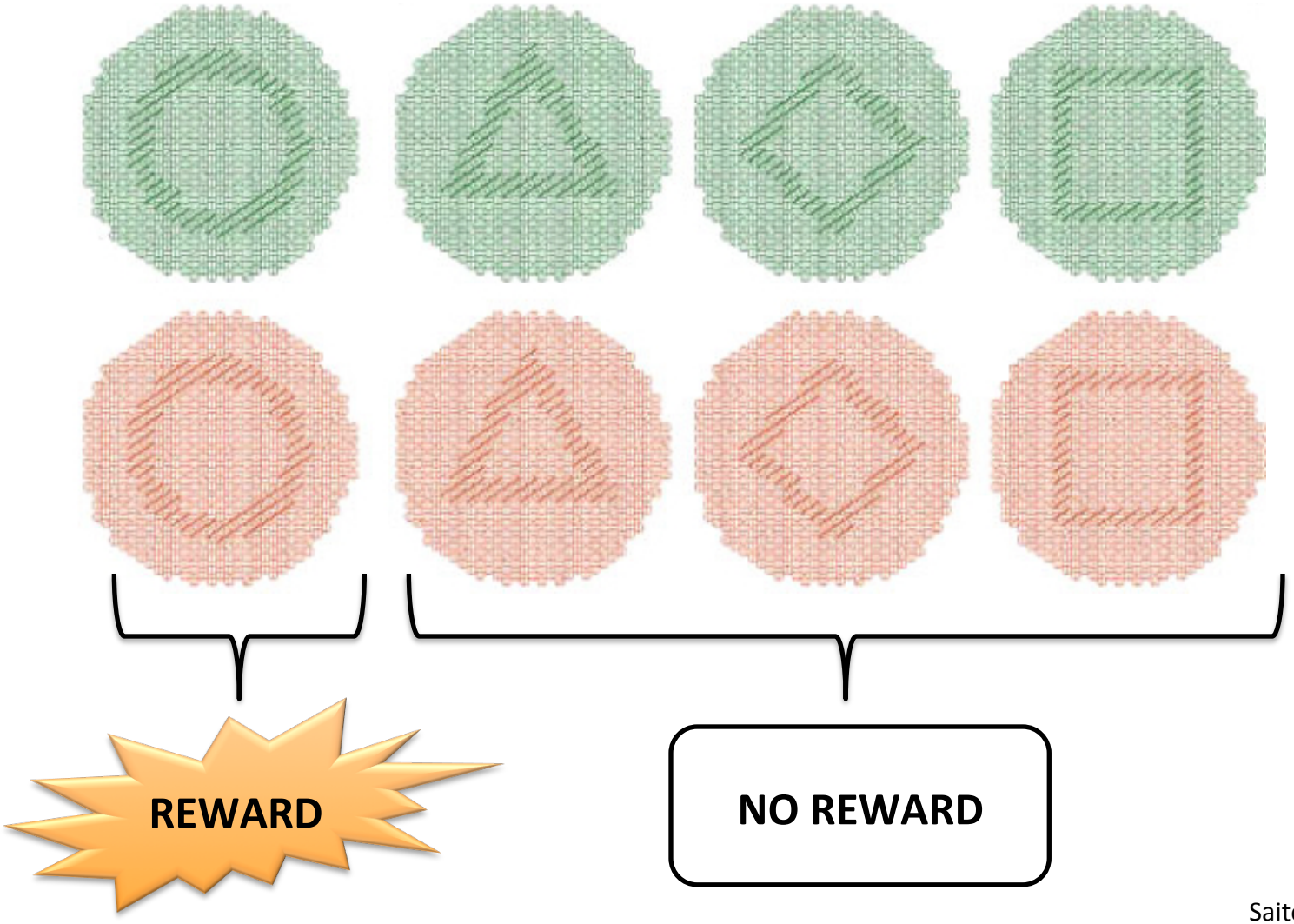
A) Almost certainly.
B) Sometimes.
C) Unsure.
D) Probably not.
E) Absolutely not.

Let's take a look…

A) Almost certainly.
B) Sometimes.
C) Unsure.
D) Probably not.
E) Absolutely not.

Food Selection – The Research

The DESIGN



Saito et al, 2005

Food Selection – The Research

The TRAINING

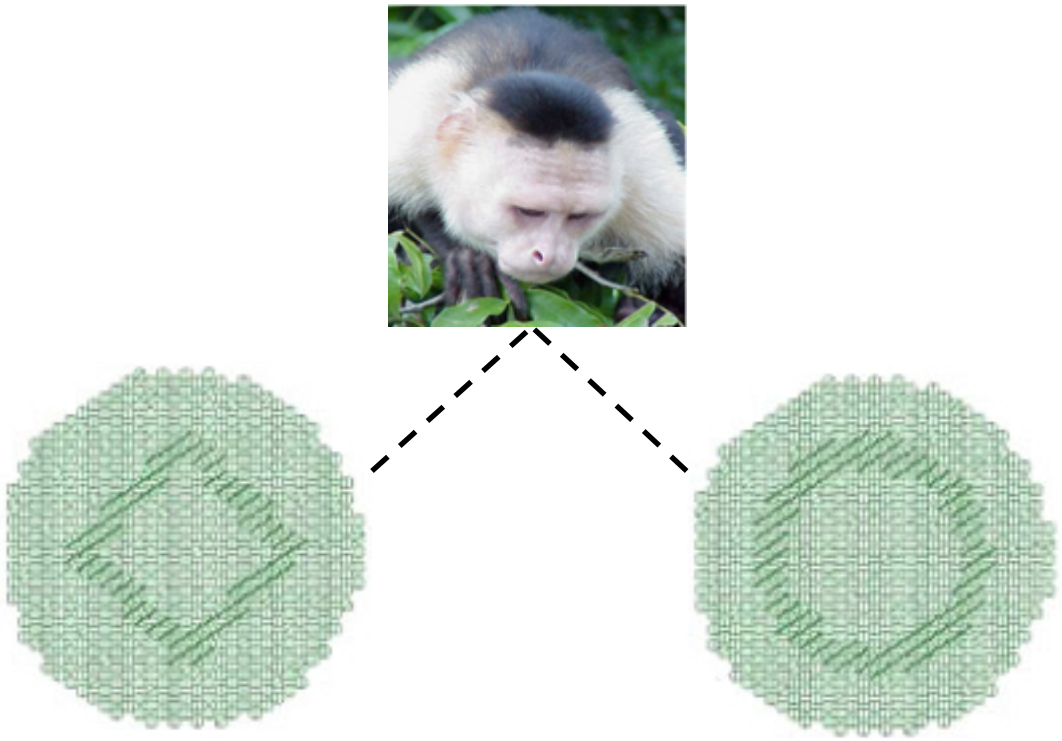


Photo: KENPEI

Saito et al, 2005

Food Selection – The Research

The TRAINING

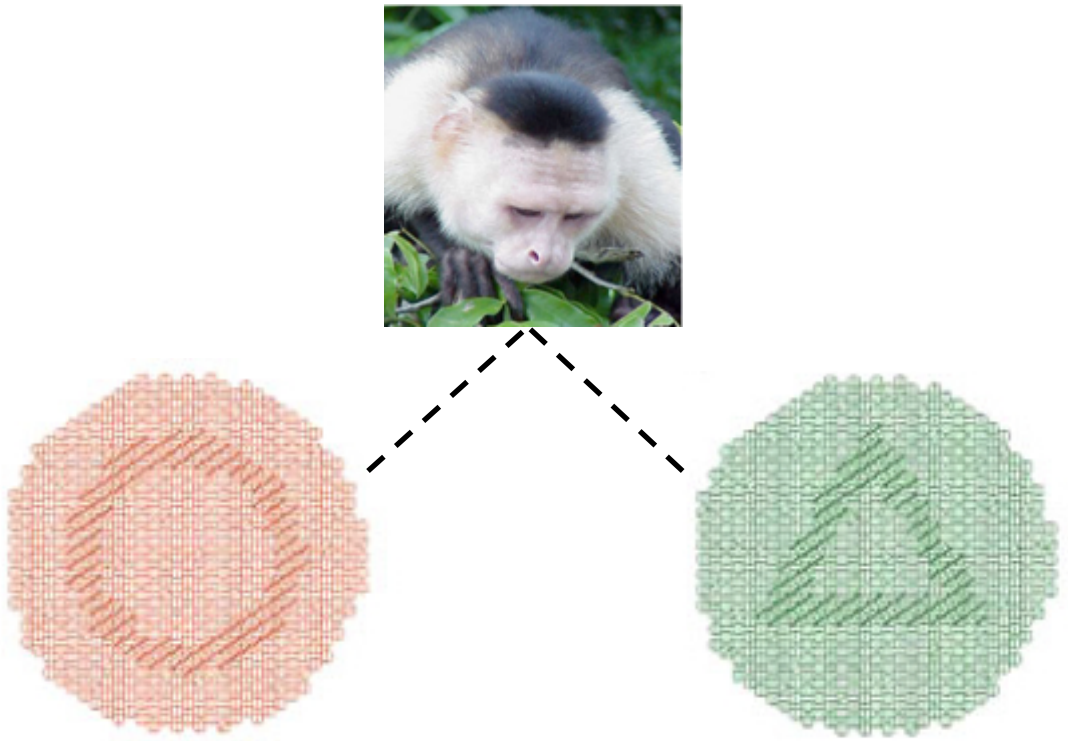
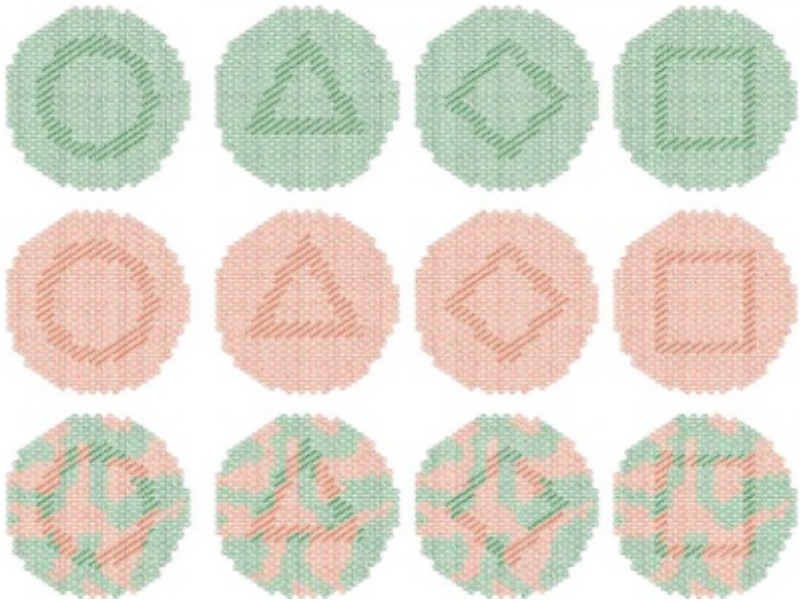


Photo: KENPEI

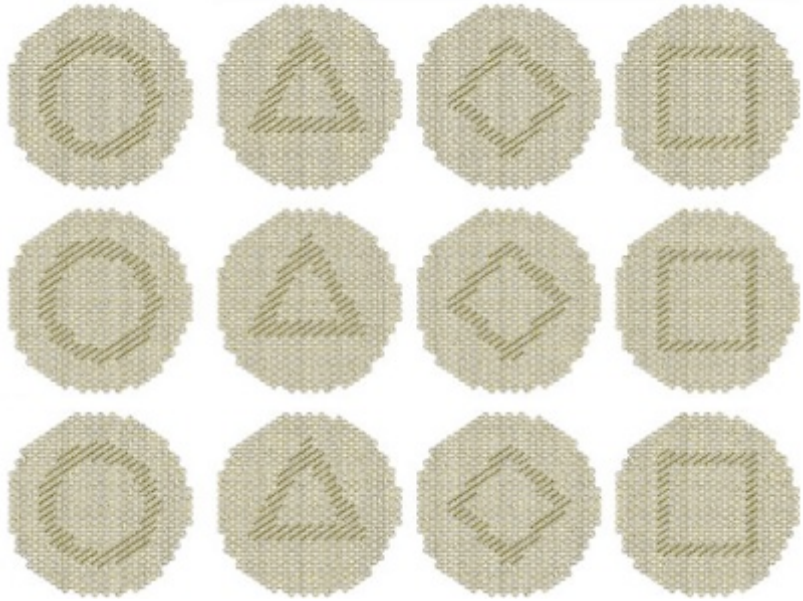
Saito et al, 2005

http://www.evo-ed.com/Pages/Primates/PatchGame/PatchGame.html

Food Selection – The Research



TRICHROMATIC VISION



DICHROMATIC VISION

Saito et al, 2005

Food Selection – The Results

The RESULTS

	TRICHROMATS	DICHROMATS
REWARD	51%	85%

Saito et al, 2005

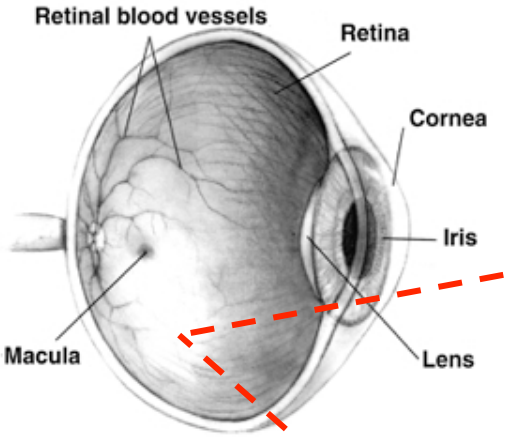
Food Selection – Summary

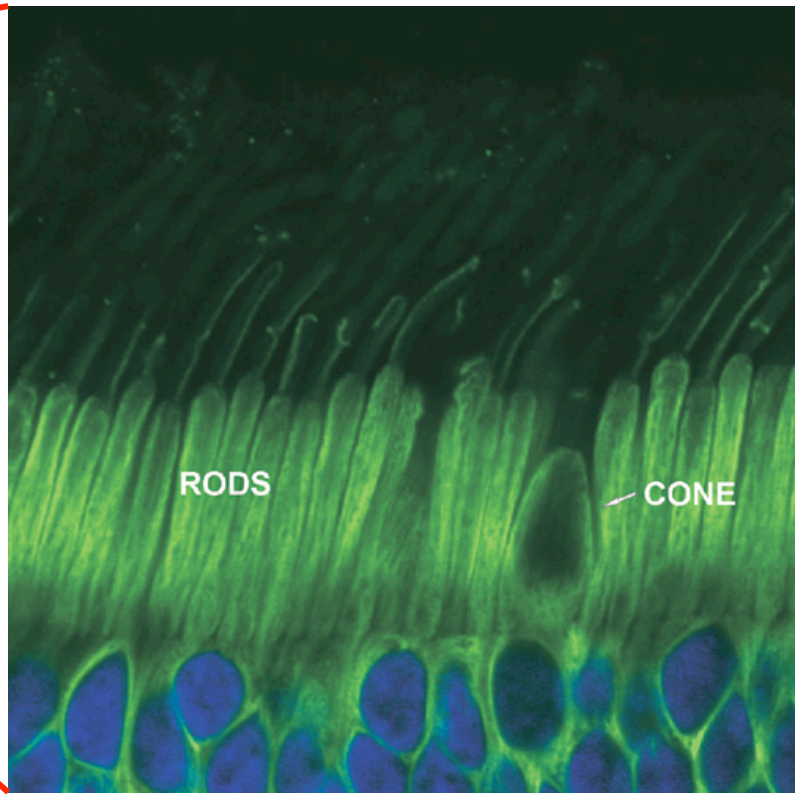
Research suggests that **trichromatic** vision is more likely to be selected for when food is distinguished from non-food by color.

Research suggests that **dichromatic** vision is more likely to be selected for when food is distinguished from non-food by shape.

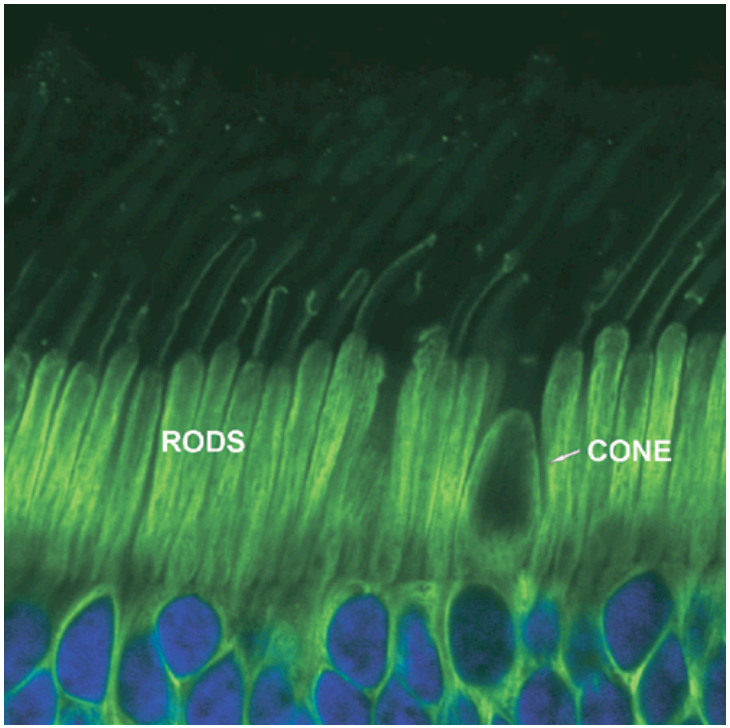
Cell Biology…

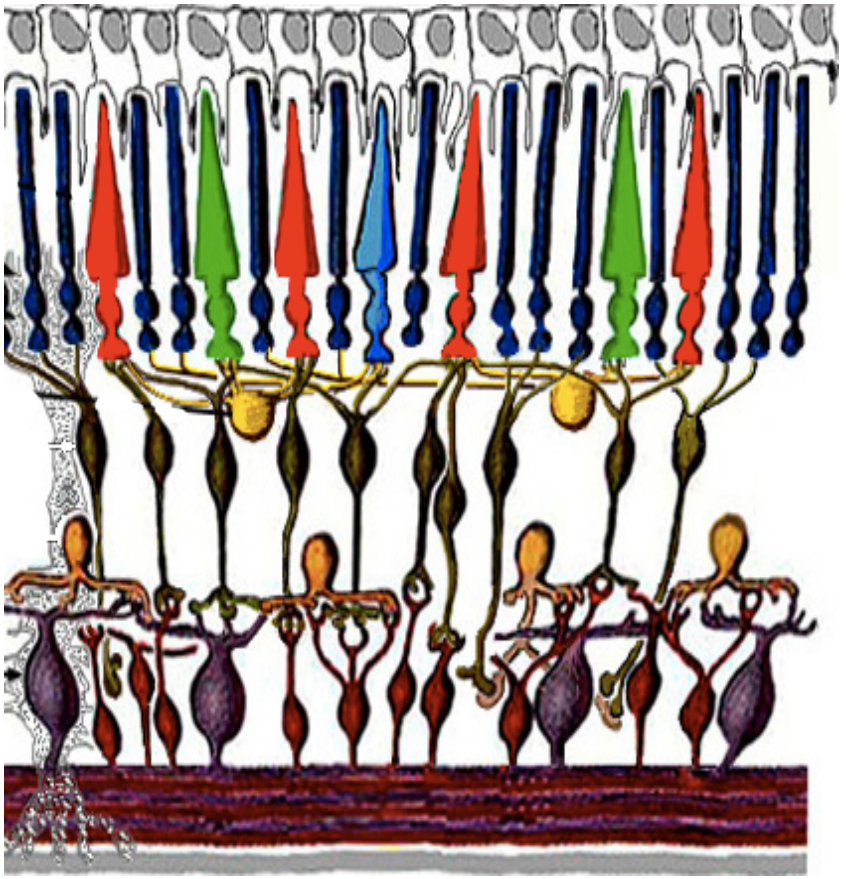
How Does Color Vision Work?
Cell Biology:





How Does Color Vision Work?





Three types of Cone Cell

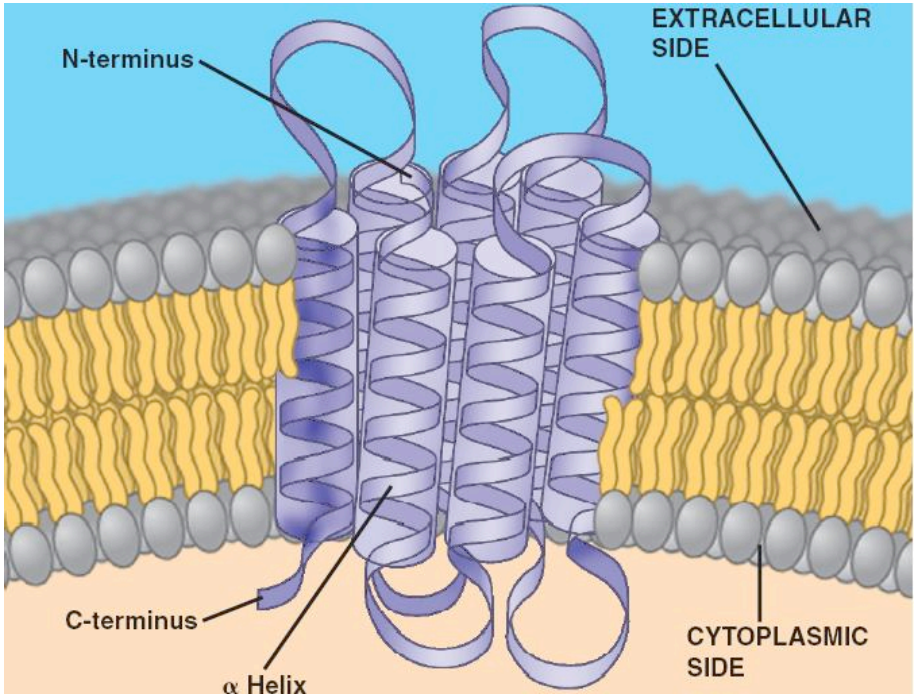
- Different kinds of opsin proteins embedded in the membrane of cone cells.

- Central Dogma of Molecular Biology:

  DNA → RNA → Protein

  Genes code for…. proteins

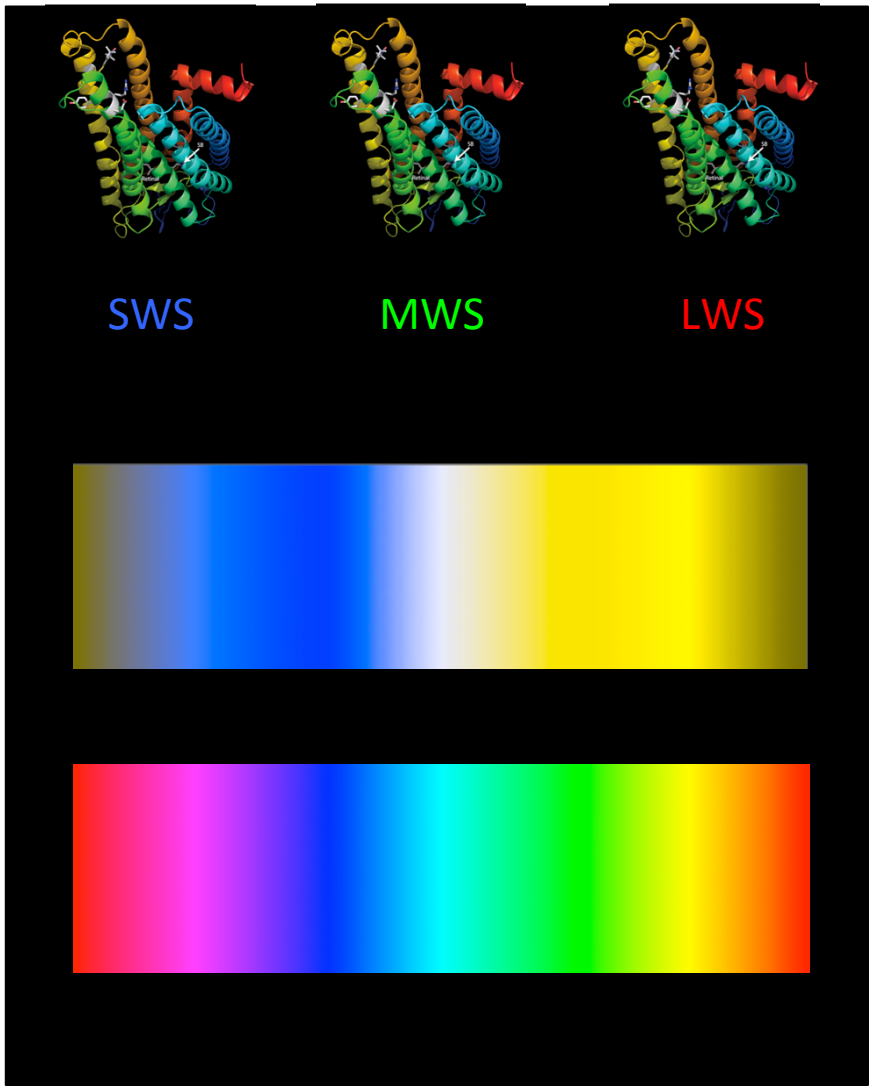
Cells and Proteins



- When an opsin protein is stimulated by a photon of light, a signal is sent to the brain and interpreted as light/color.

A transmembrane protein: Image 7.8 from Biology 8th Ed. (Campbell and Reece)

The Role of Opsins

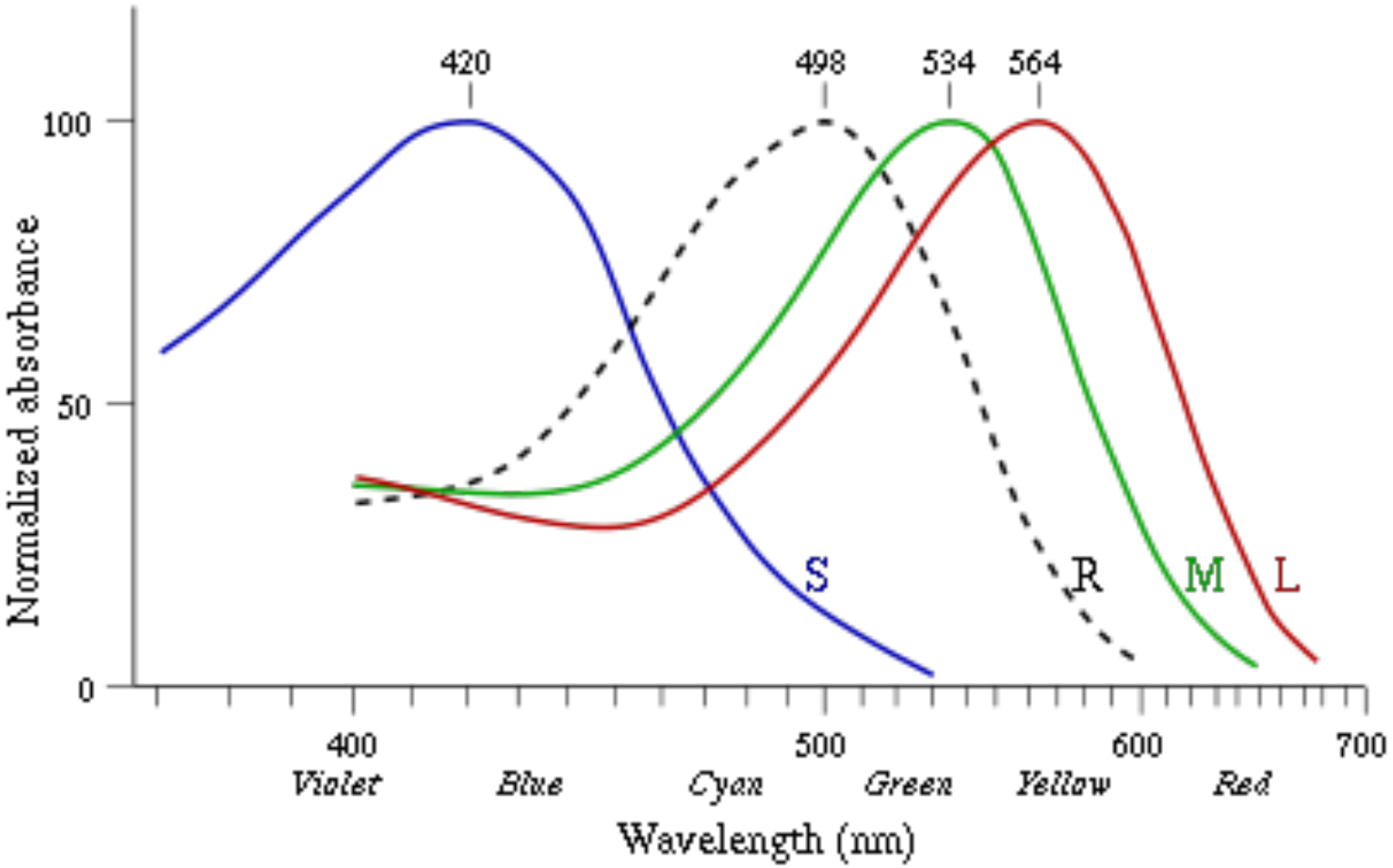


There are three types of opsins:
Short Wave Sensitive (SWS)
Medium Wave Sensitive (MWS)
Long Wave Sensitive (LWS)

An individual possessing only SWS and MWS opsins will have dichromatic vision.

An individual possessing SWS, MWS and LWS opsins will have trichromatic vision.

Opsin Response to Light



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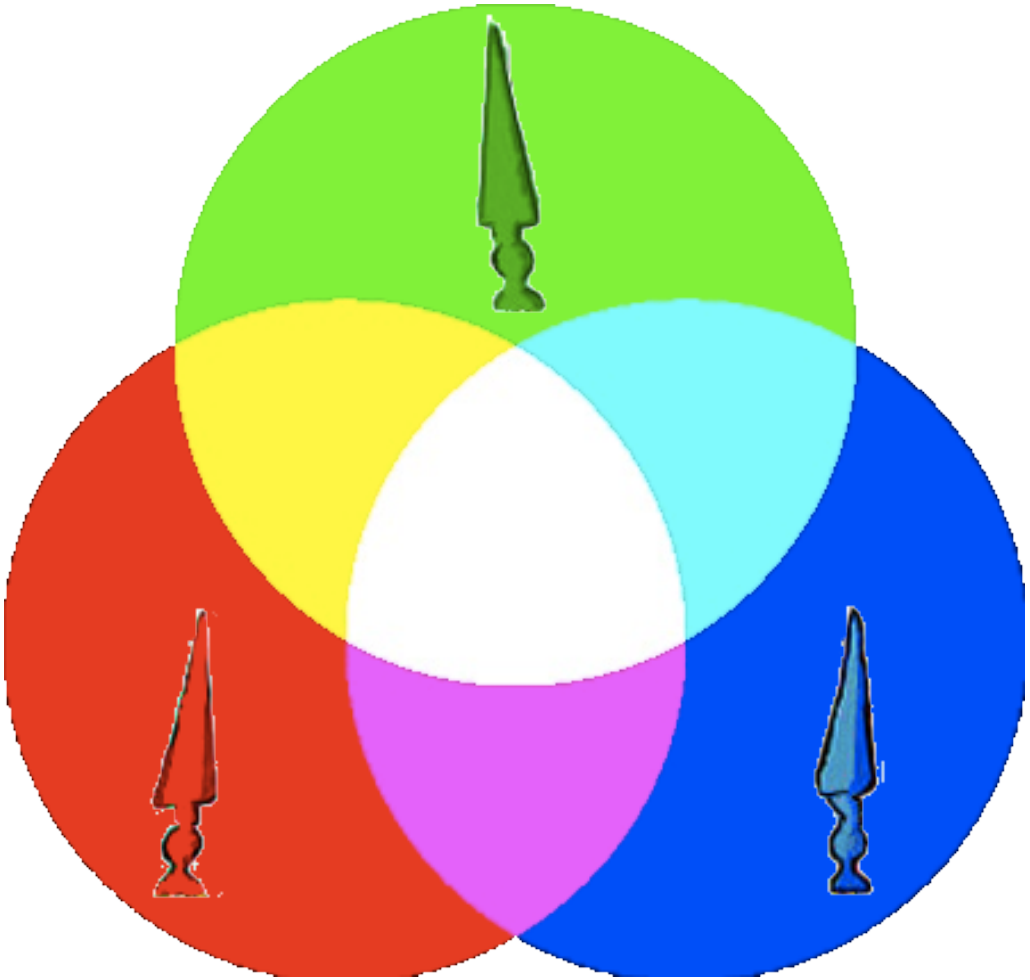
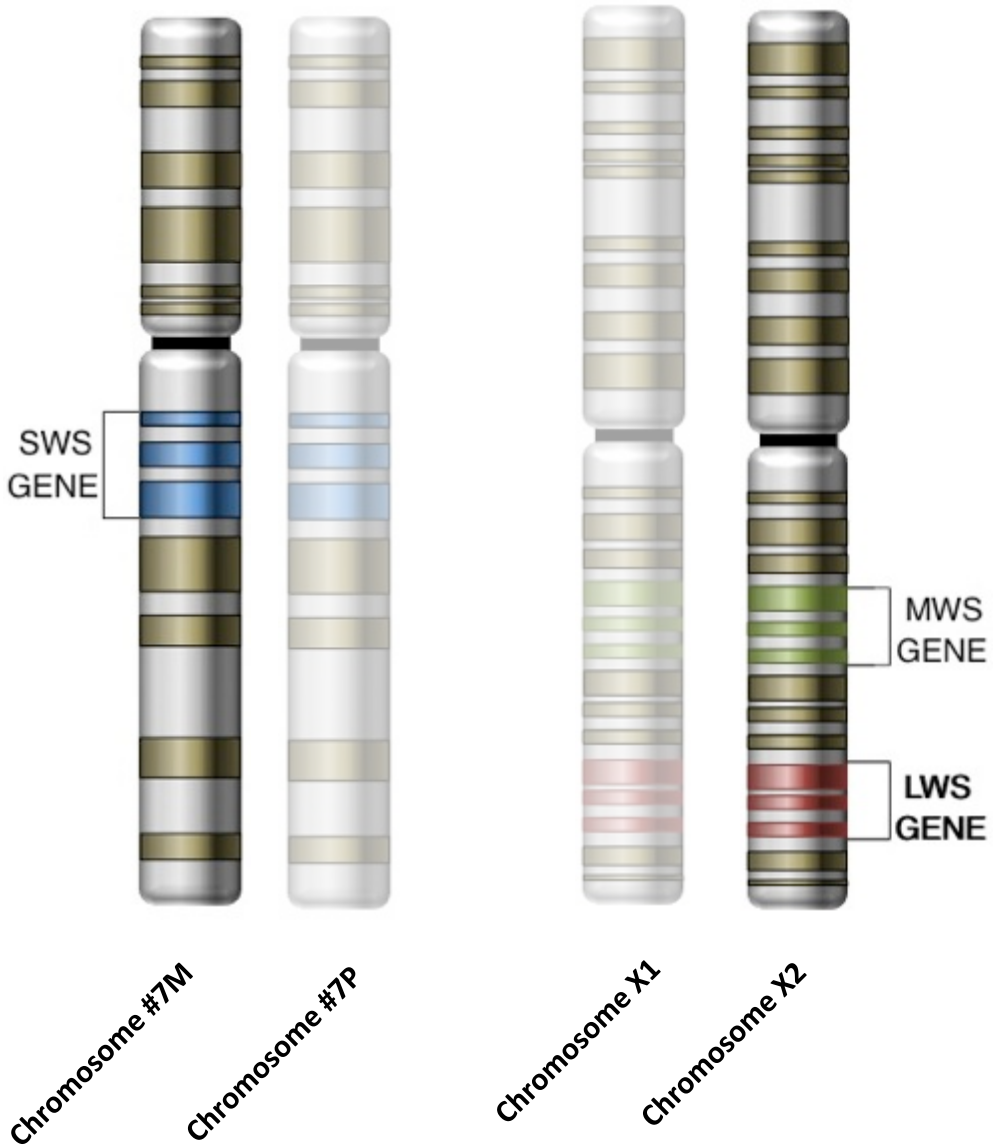


Genetics…

Location of Opsin Genes

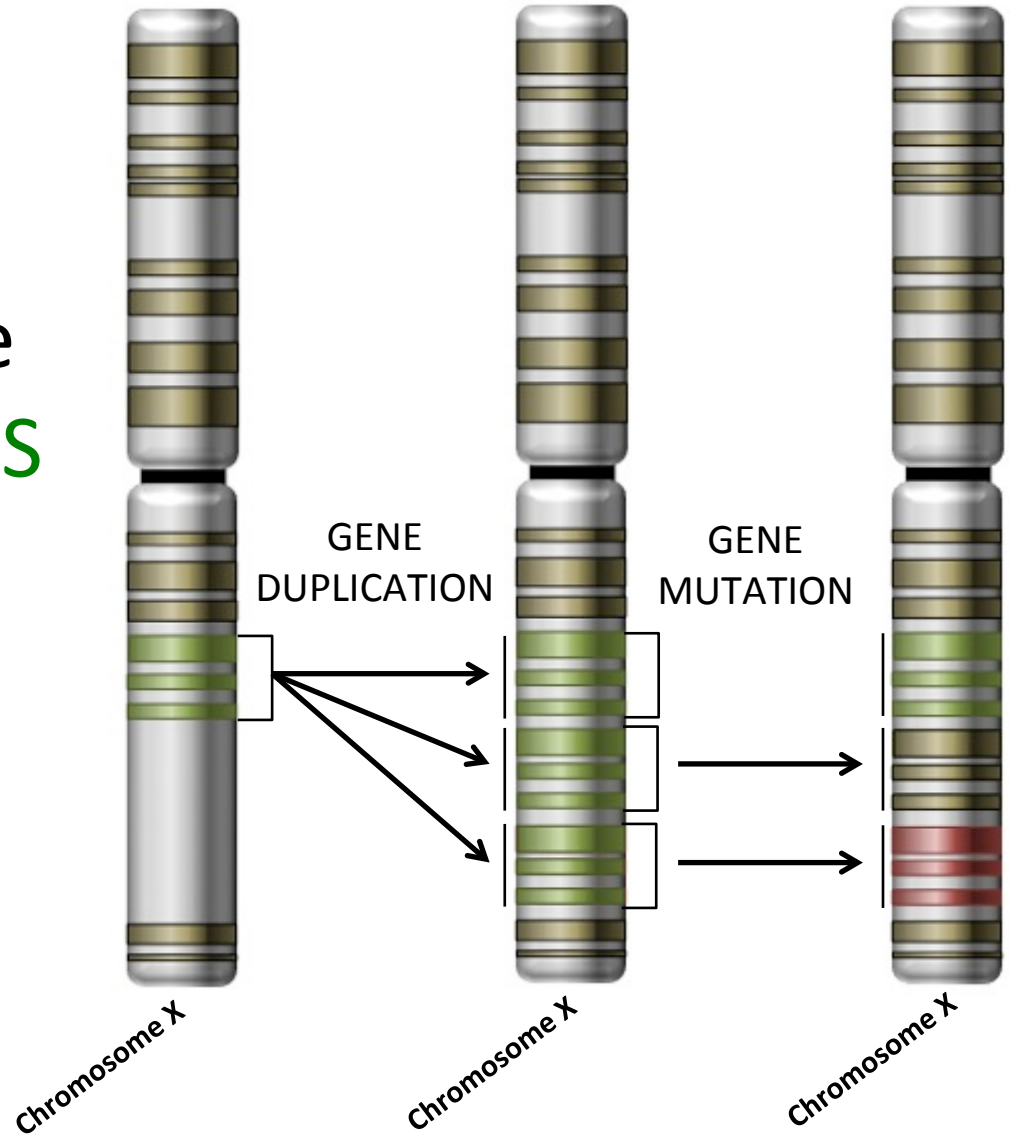
The gene coding for the SWS opsin protein is located on chromosome #7.

The gene coding for the MWS and LWS opsins are located on the X-chromosome.



Evolution of the LWS Opsin Gene

The LWS gene arose through gene duplication and gene mutation of the MWS gene on the X-chromosome.



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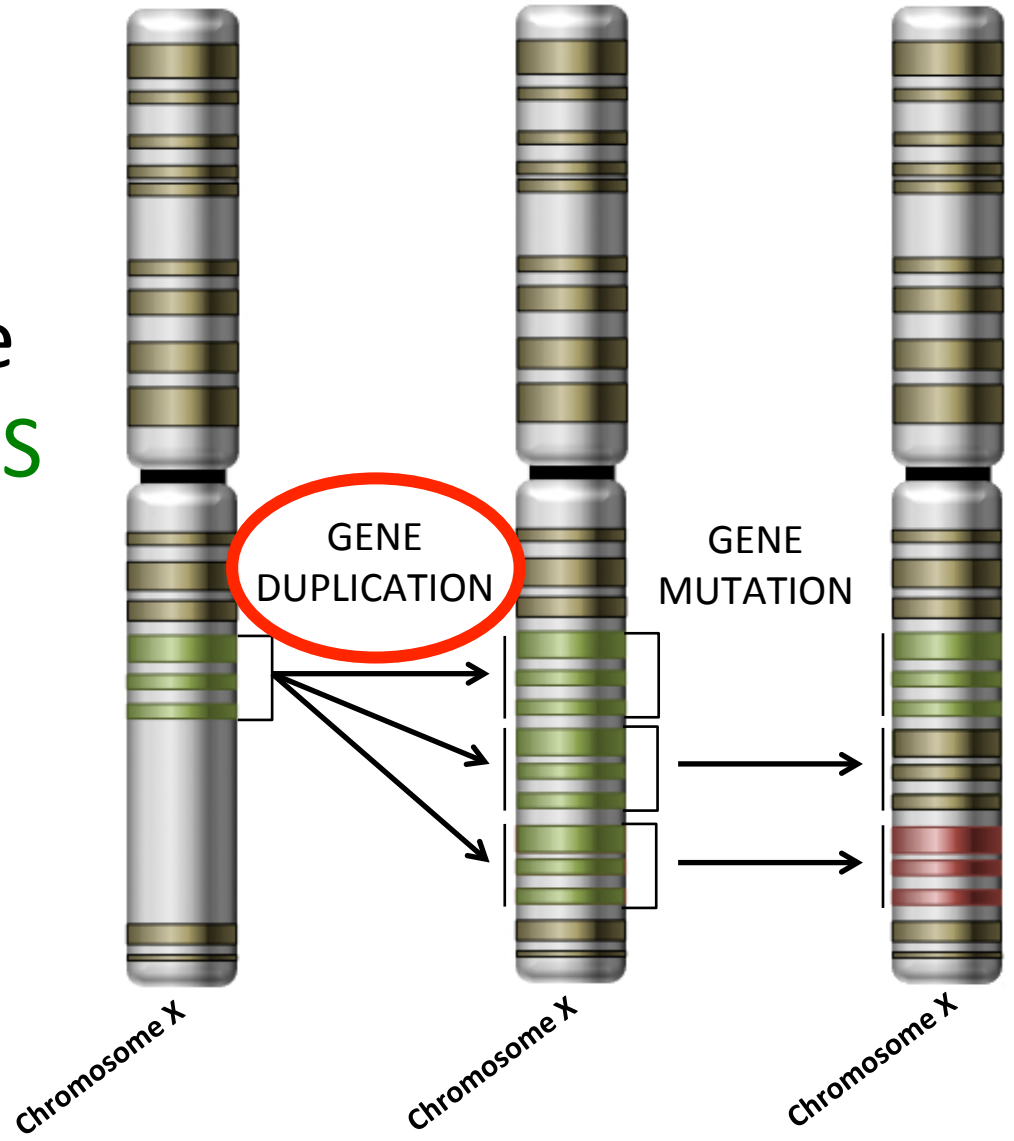
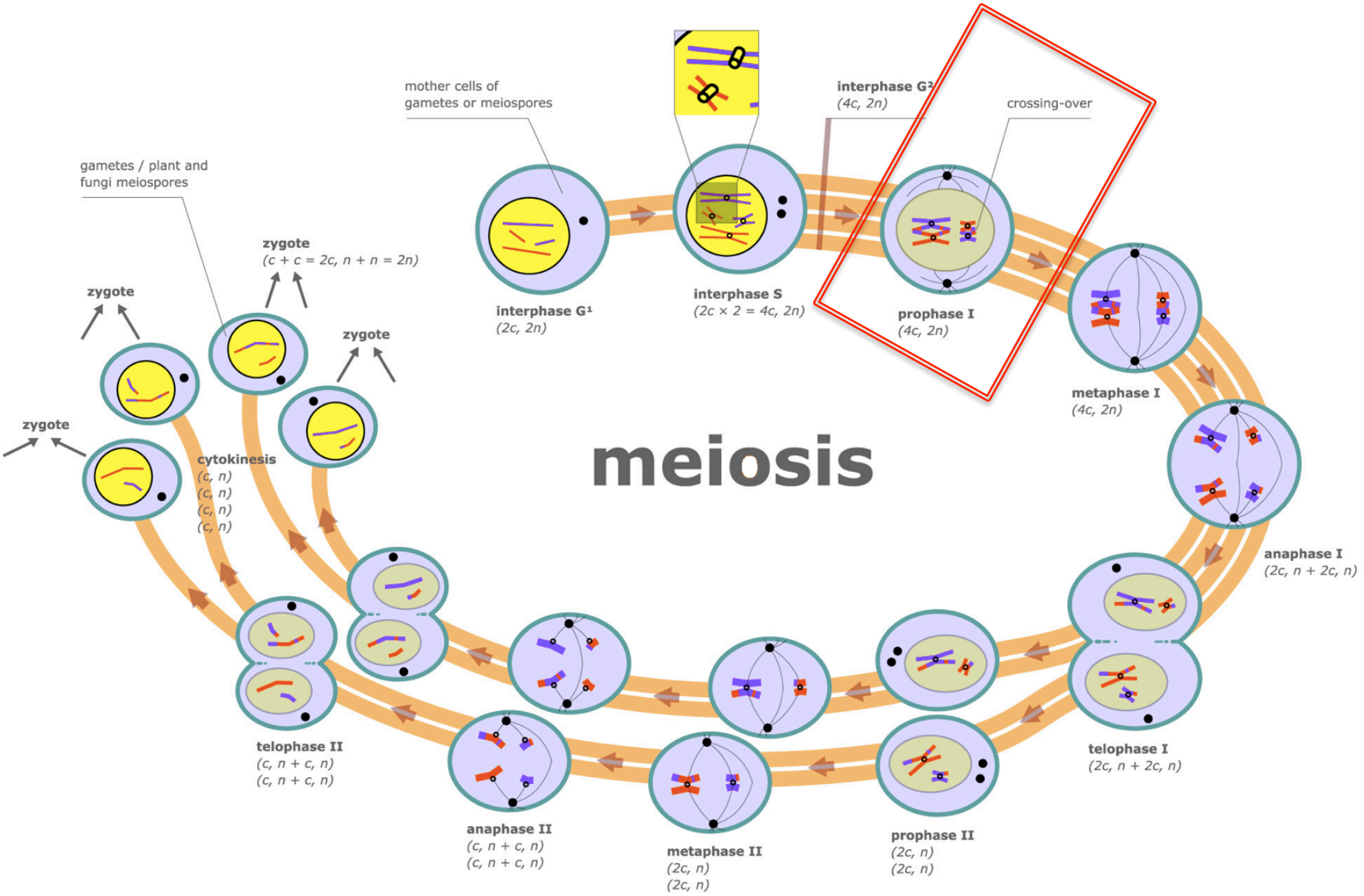
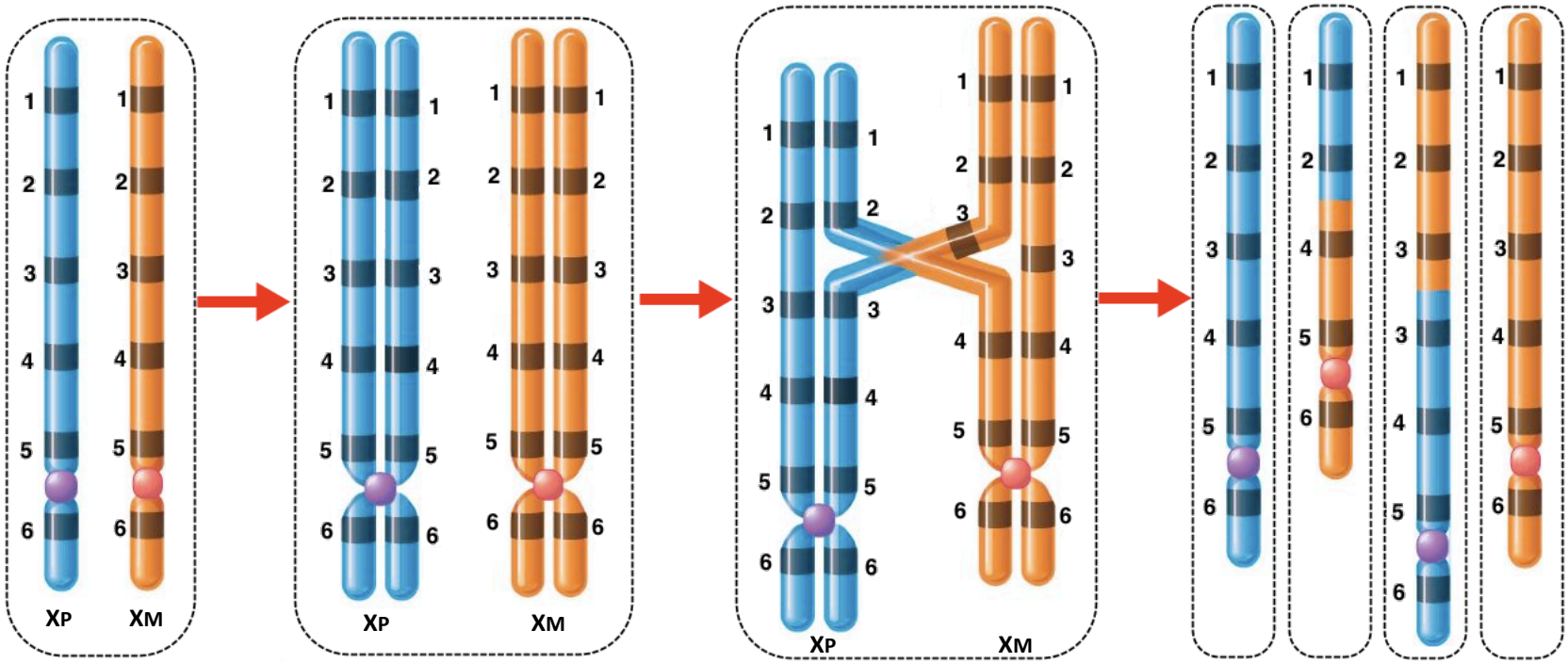


Gene Duplication



Unequal Crossing Over

(Meiosis, Prophase 1)



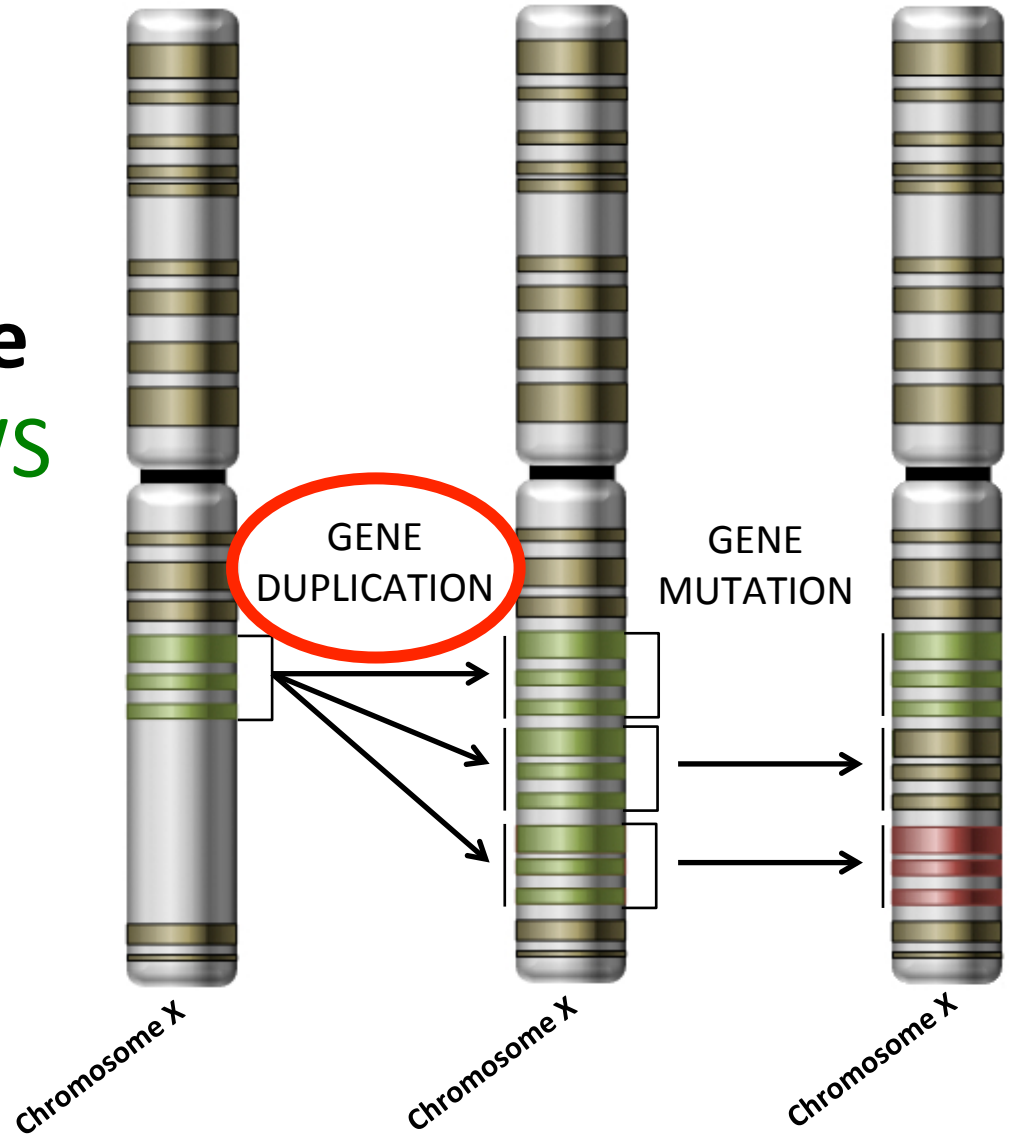
Interphase S

Prophase I

…Telophase II

Evolution of the LWS Opsin Gene

The LWS gene arose through **gene duplication** and **gene mutation** of the MWS gene on the X-chromosome.



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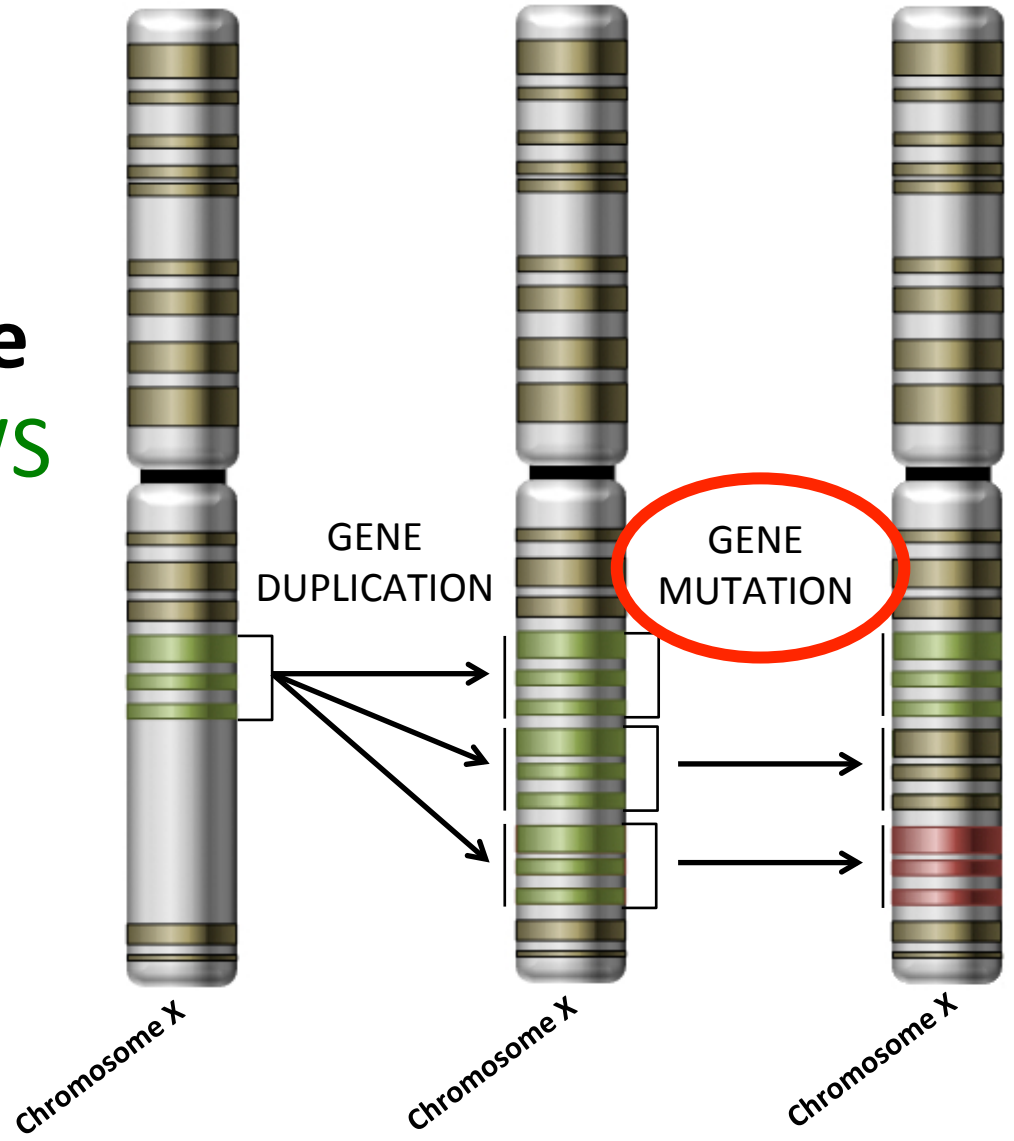

MWS Opsin Gene vs. **LWS** Opsin Gene

(functional differences)

MWS GENE

atggcccagcagtggagcctccaaaggctcgcaggccgccatccgcaggacagctatgaggacagcacccagtccagcatcttcac
ctacaccaacagcaactccaccagaggccccttcgaaggcccgaattaccacatcgctcccagatgggtgtaccacctcaccagtg
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LWS GENE

atggcccagcagtggagcctccaaaggctcgcaggccgccatccgcaggacagctatgaggacagcacccagtccagcatcttcac
ctacaccaacagcaactccaccagaggccccttcgaaggcccgaattaccacatcgctcccagatgggtgtaccacctcaccagtg
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tctgaactctccagcgcctccaaaacggaggtctcatctgtgtcctcggtatcgcctgcatga

MWS Opsin Gene vs. **LWS** Opsin Gene

(functional differences)

MWS GENE

atggcccagcagtggagcctccaaaggctcgcaggccgccatccgcaggacagctatgaggacagcacccagtccagcatcttcac
ctacaccaacagcaactccaccagaggccccttcgaaggcccgaattaccacatcgctcccagatgggtgtaccacctcaccagtg
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tctgaactctccagcgcctccaaaacggaggtctcatctgtgtcctcggtatcgcctgcatga

LWS GENE

atggcccagcagtggagcctccaaaggctcgcaggccgccatccgcaggacagctatgaggacagcacccagtccagcatcttcac
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tctgaactctccagcgcctccaaaacggaggtctcatctgtgtcctcggtatcgcctgcatga

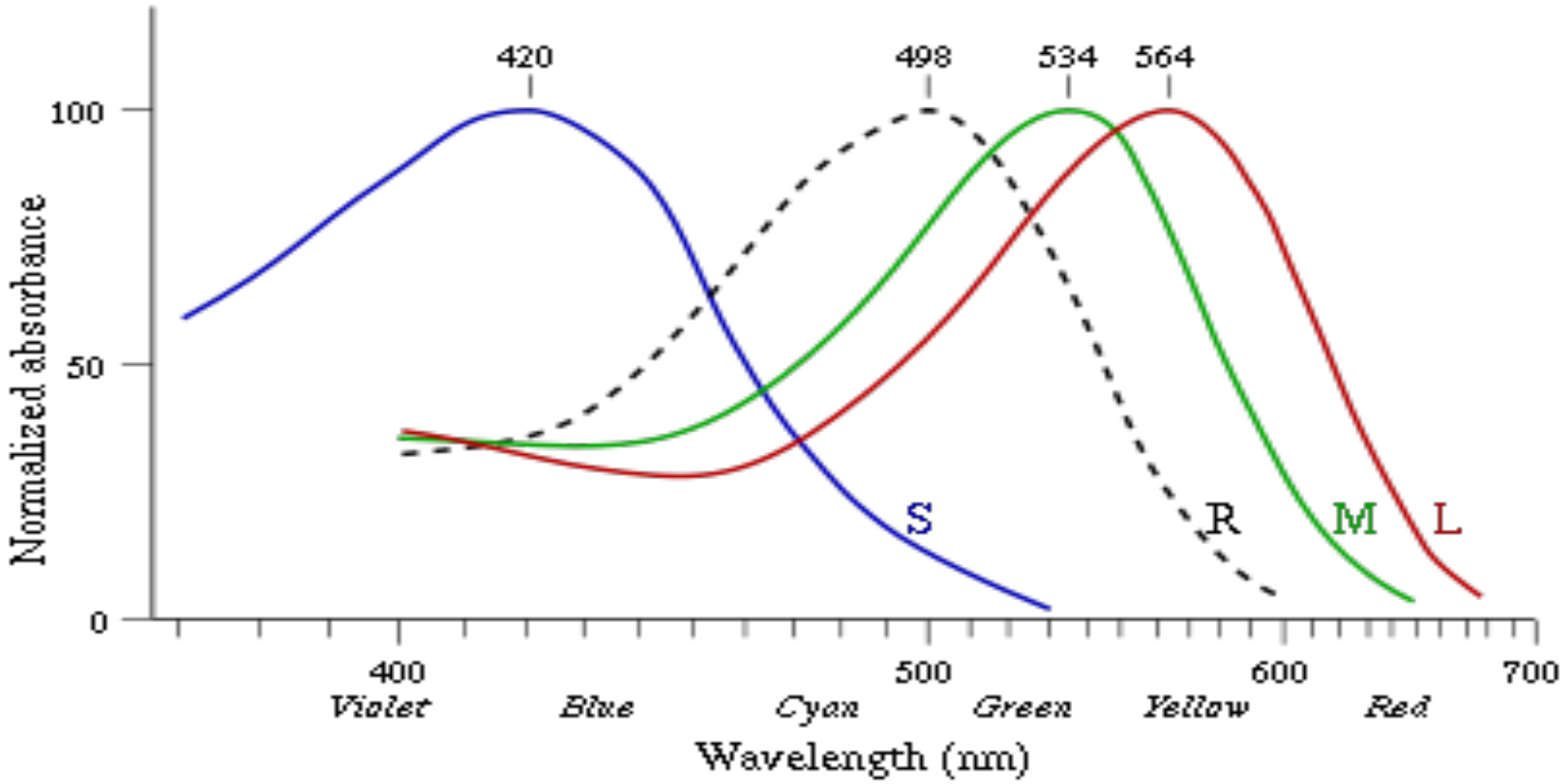
MWS Opsin Gene vs. **LWS** Opsin Gene

(functional differences)

G → T T → A G → A

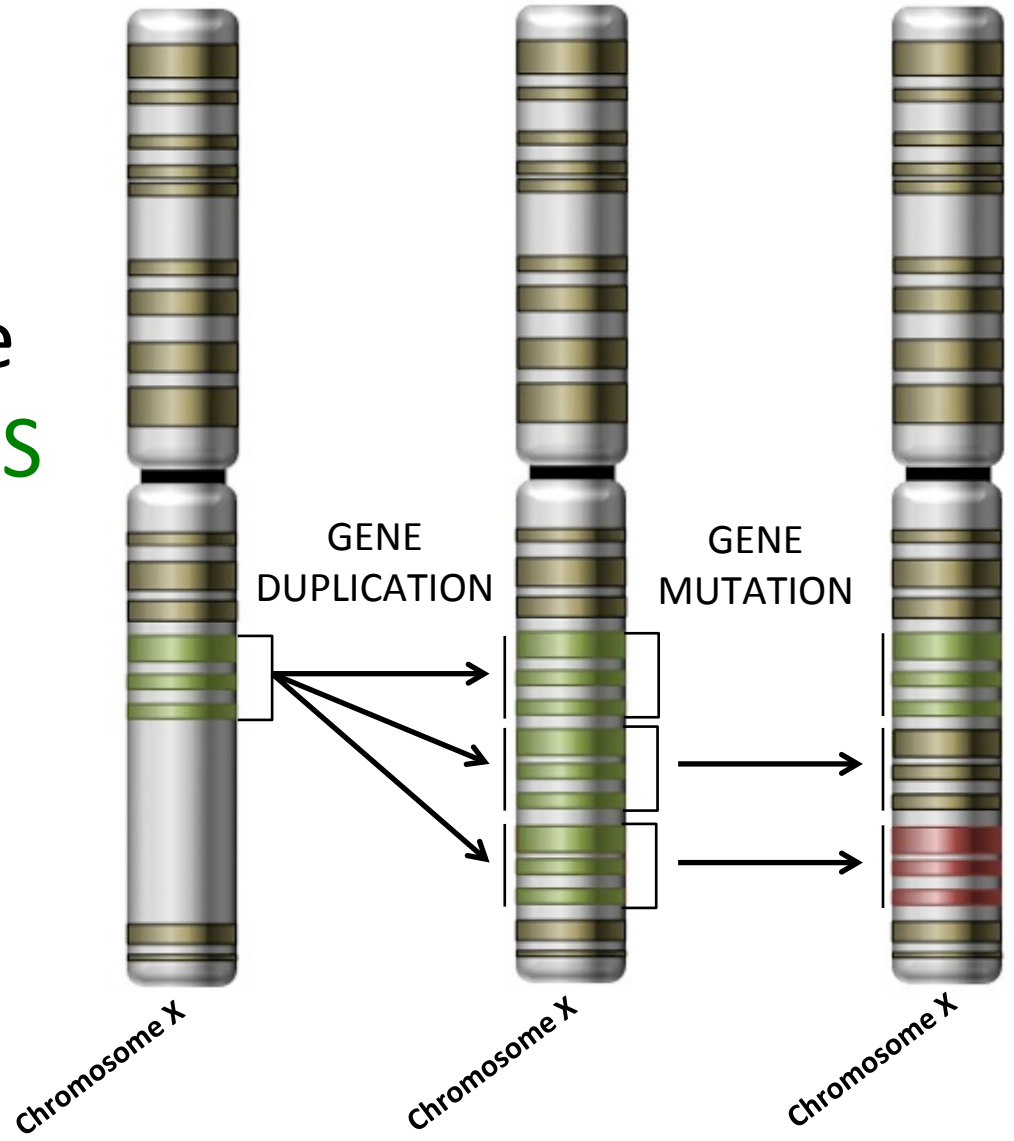
- Three simple substitution mutations change the properties of the opsin protein.
- Now, rather than being maximally stimulated at 534nm, the resulting opsin protein is maximally stimulated at 564nm.

What difference does this make?



Evolution of the LWS Opsin Gene

The LWS gene arose through gene duplication and gene mutation of the MWS gene on the X-chromosome.

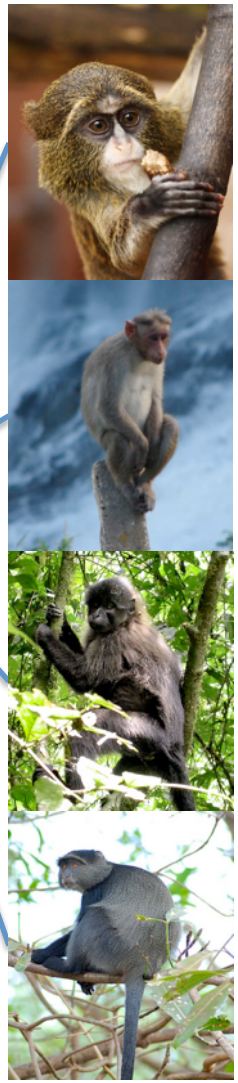


Phylogenetics, Biogeography and more…

Biogeography of Global Monkeys

FULL COLOR VISION

OLD WORLD

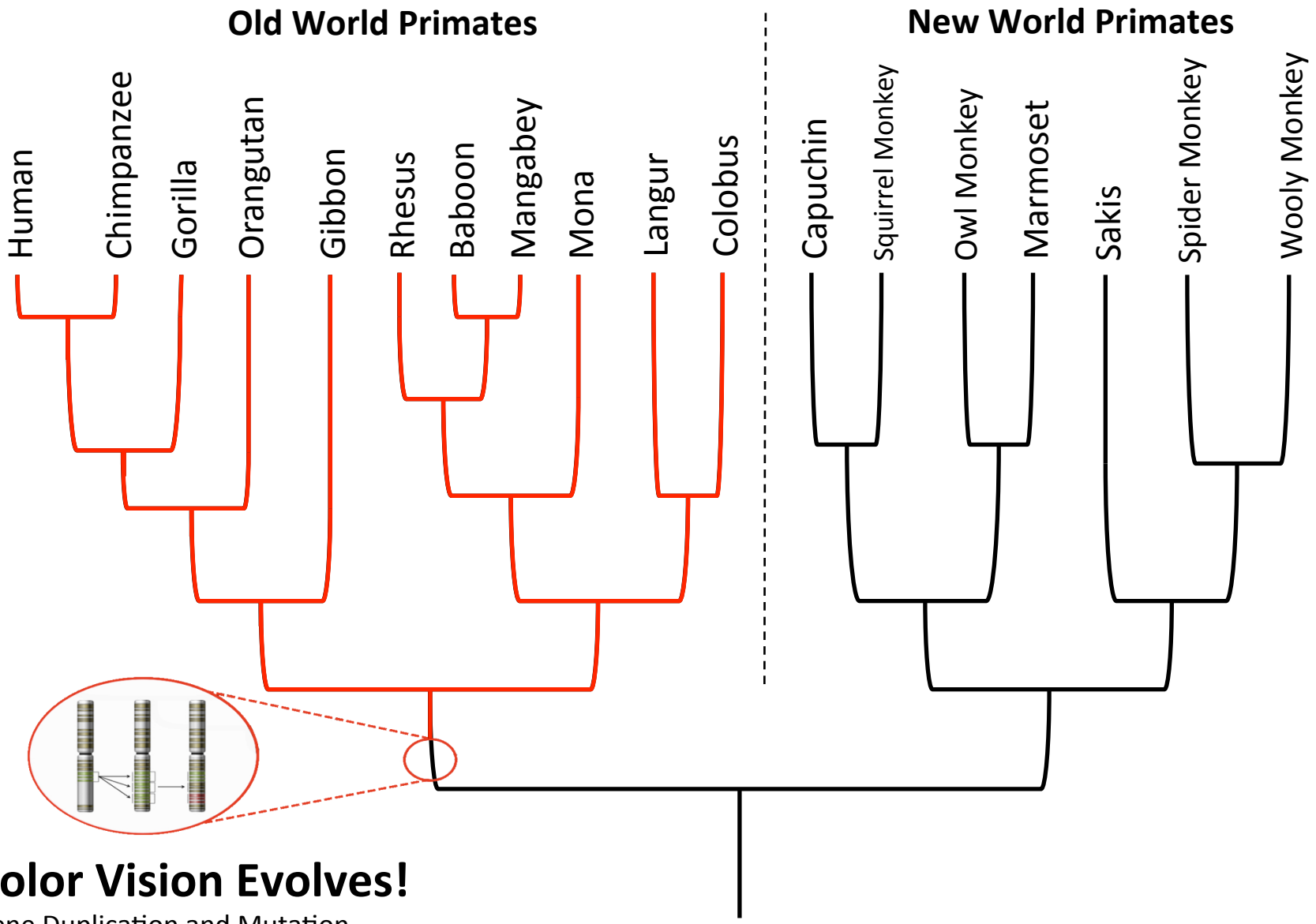


COLOR BLIND

NEW WORLD

Photo: Frans de Waal, M Arunprasaad, D Wright, P Gonnet, L DeVoldor, W Endo

Phylogenetics – Exploring Relationships Among Species



Color Vision Evolves!

Gene Duplication and Mutation

Geology: Plate Tectonics and Drift

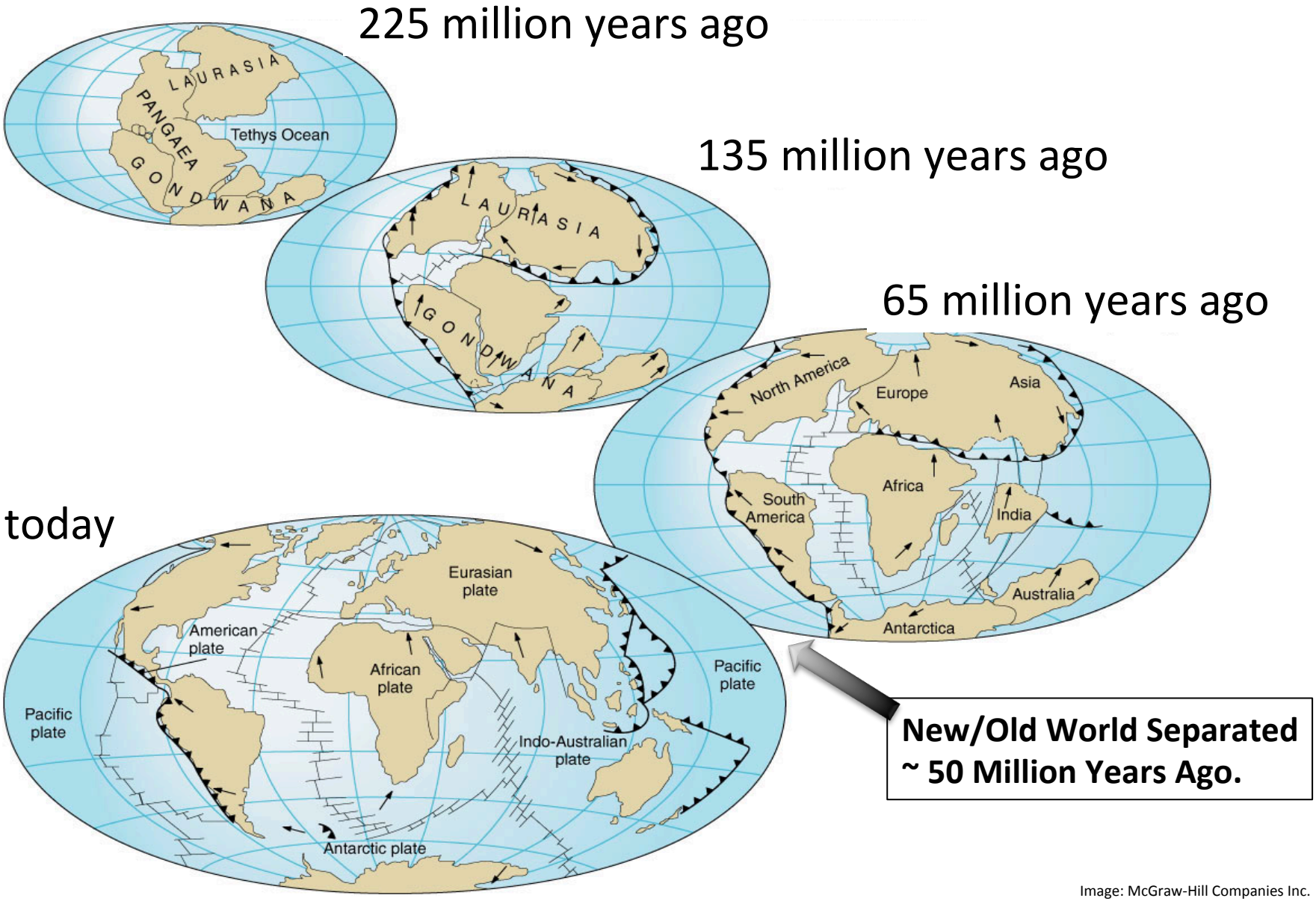


Image: McGraw-Hill Companies Inc.

How Old are Primates?

BMC Evolutionary Biology

BioMed Central

Research article

Open Access

Estimating the phylogeny and divergence times of primates using a supermatrix approach

Helen J Chatterjee*†1, Simon YW Ho†2,3, Ian Barnes†4 and Colin Groves†5

Comparative Genomics and Molecular Evolution

Cytogenet Genome Res 108:26–37 (2005)
DOI: 10.1159/000080799

Cytogenetic and Genome Research

Primate phylogeny: molecular evidence from retroposons

J. Schmitz,[a] C. Roos[b] and H. Zischler[c]

SCIENCE'S COMPASS

PERSPECTIVES: PALEONTOLOGY

Primate Origins Nailed

Eric J. Sargis

MOLECULAR PHYLOGENETICS AND EVOLUTION
Vol. 5, No. 1, February, pp. 102–154, 1996
ARTICLE NO. 0009

Primate Phylogeny: Morphological vs Molecular Results

JEHESKEL SHOSHANI,* COLIN P. GROVES,† ELWYN L. SIMONS,‡ AND GREGG F. GUNNELL§

REVIEW

Paleontological Evidence to Date the Tree of Life

Michael J. Benton and Philip C. J. Donoghue

~70-80
Million Years Ago

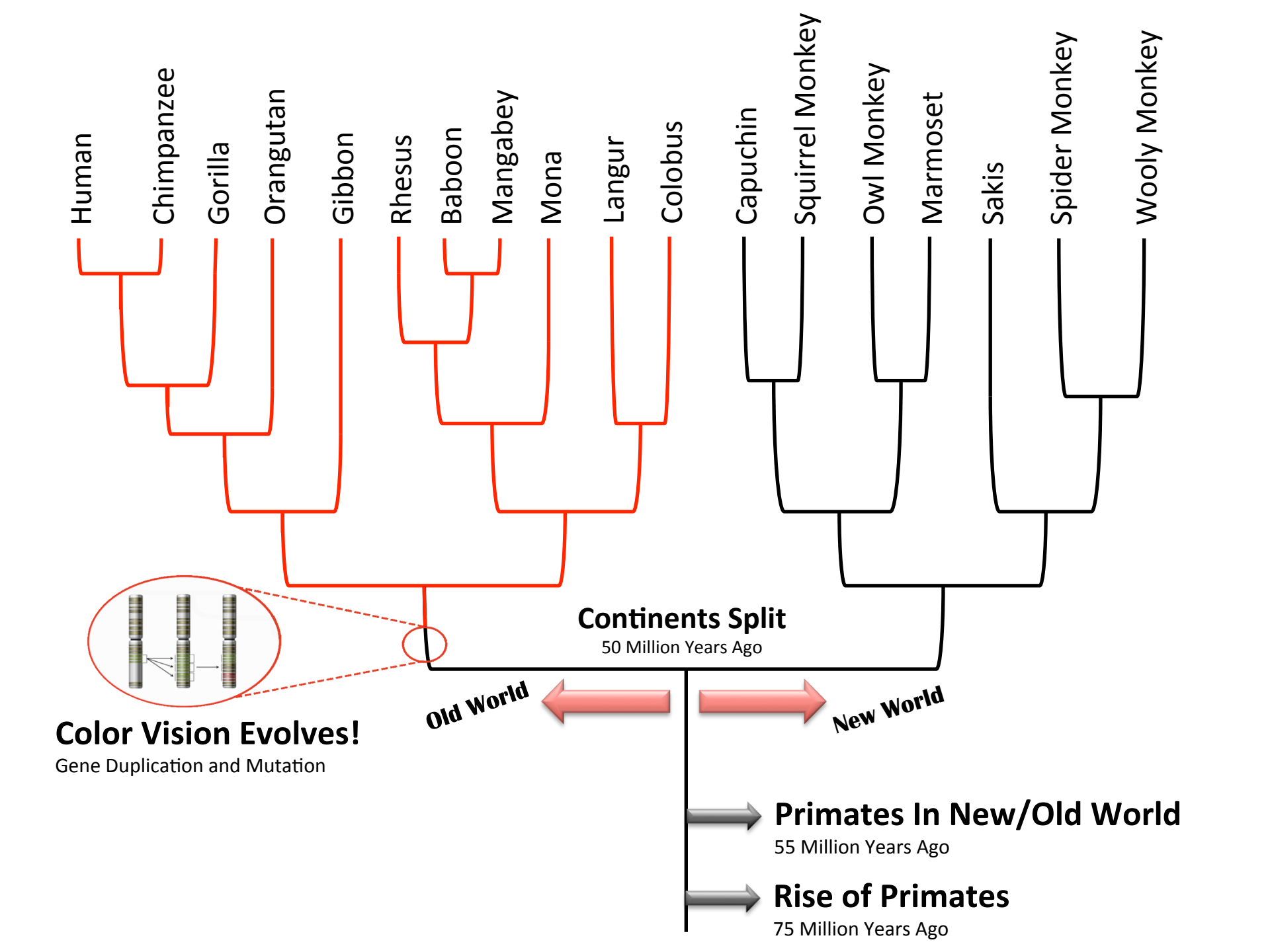
When did primates first inhabit N. America?

Oldest Primate Fossil in North America Discovered

John Roach
for National Geographic News
March 3, 2008

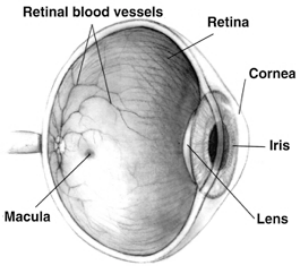
A newly found species small enough to fit in the palm of a hand is North America's oldest known primate, according to a new study.

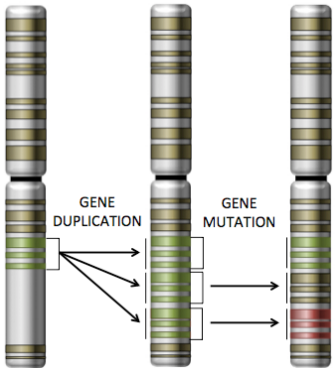
Christopher Beard, a paleontologist at the Carnegie Museum of Natural History in Pittsburgh, Pennsylvania, recently discovered fossils of the 55-million-year-old creature on the Gulf Coastal Plain of Mississippi.

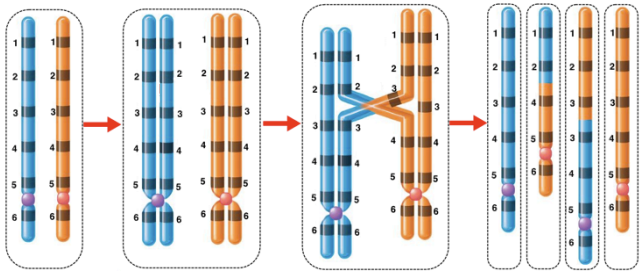

Human
Chimpanzee
Gorilla
Orangutan
Gibbon
Rhesus
Baboon
Mangabey
Mona
Langur
Colobus
Capuchin
Squirrel Monkey
Owl Monkey
Marmoset
Sakis
Spider Monkey
Wooly Monkey
Continents Split
50 Million Years Ago
Old World
New World
Color Vision Evolves!
Gene Duplication and Mutation
Primates In New/Old World
55 Million Years Ago
Rise of Primates
75 Million Years Ago

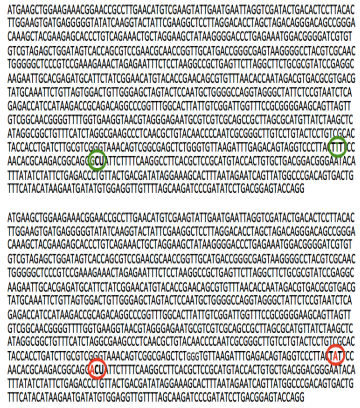
Complete Evolutionary Picture

- Genetics
- Cell Biology
- Biogeography
- Ecology
- Phylogenetics
- Paleontology
- Geology









Is there a relationship between the case approach and learning?

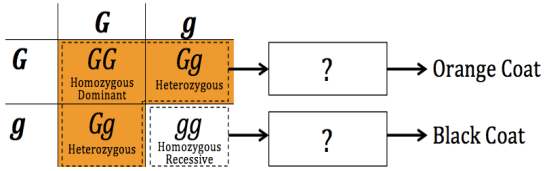
The **A**ssessment **T**ool for **E**valuating **E**volution **K**nowledge (**ATEEK**)

- Iterative design process (Anderson and Bishop 1990)
  1. Determine essential concepts important to evolution.
  2. Design an assessment tool that probes for those concepts.
  3. Field test the assessment tool.
  4. Evaluate student responses. Revise a given question if the pattern of responses differs from the expected pattern.
  5. Field test the revised assessment tool.
  6. Repeat steps 4 and 5 until satisfied with the pattern of answers.

The ATEEK

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 inside its cells 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.

Scoring the ATEEK

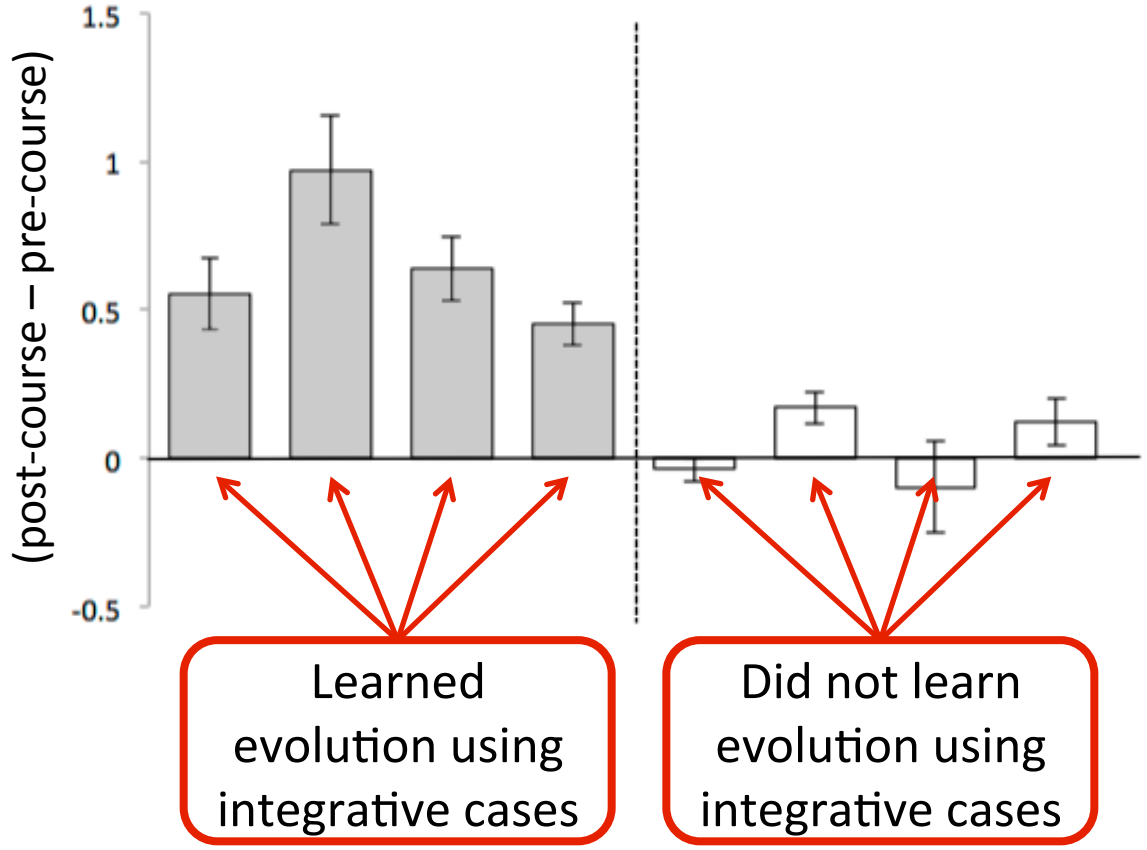
- Each response was scored as a 0, 1, or 2.
  - 0: Answer is wrong of mostly wrong.
  - 1: Answer is partially right.
  - 2: Answer is completely correct or mostly correct.

→ Average improvement calculated for each question

= Post-Course ATEEK Score – Pre-Course ATEEK Score

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 inside its cells so that a black coat is produced?



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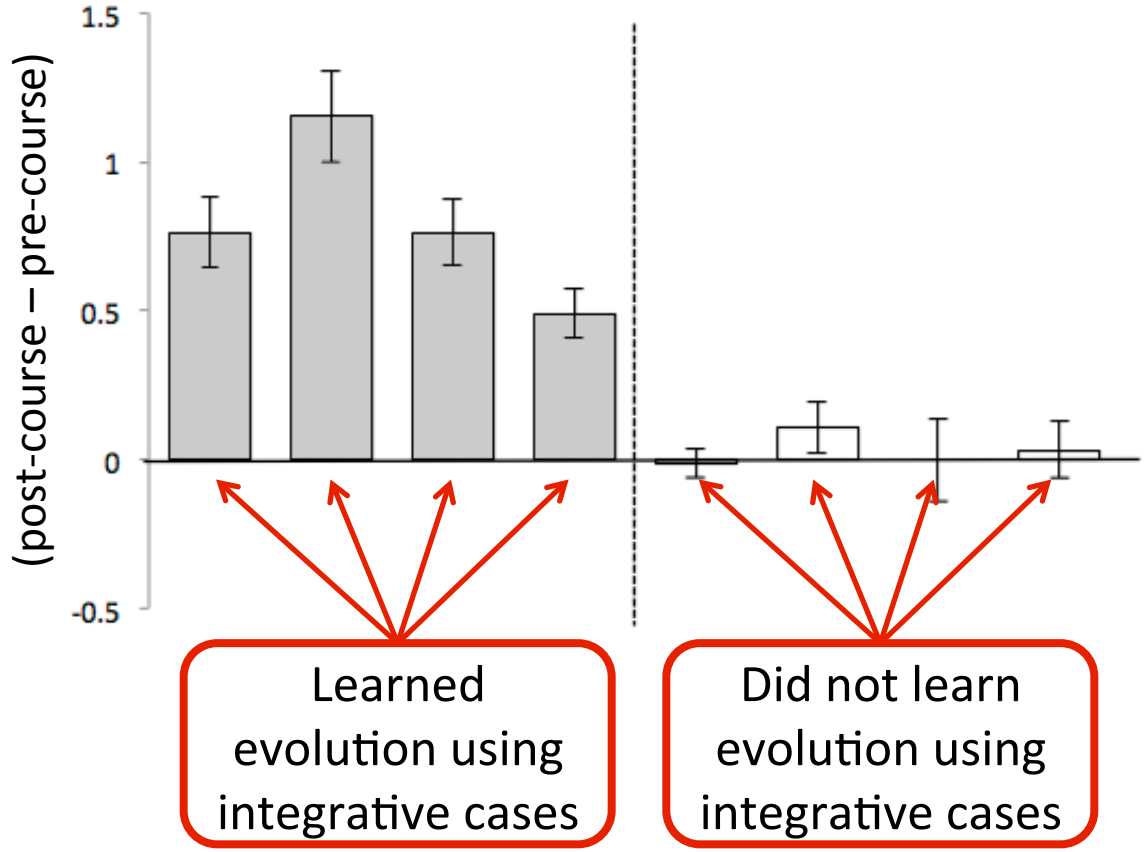
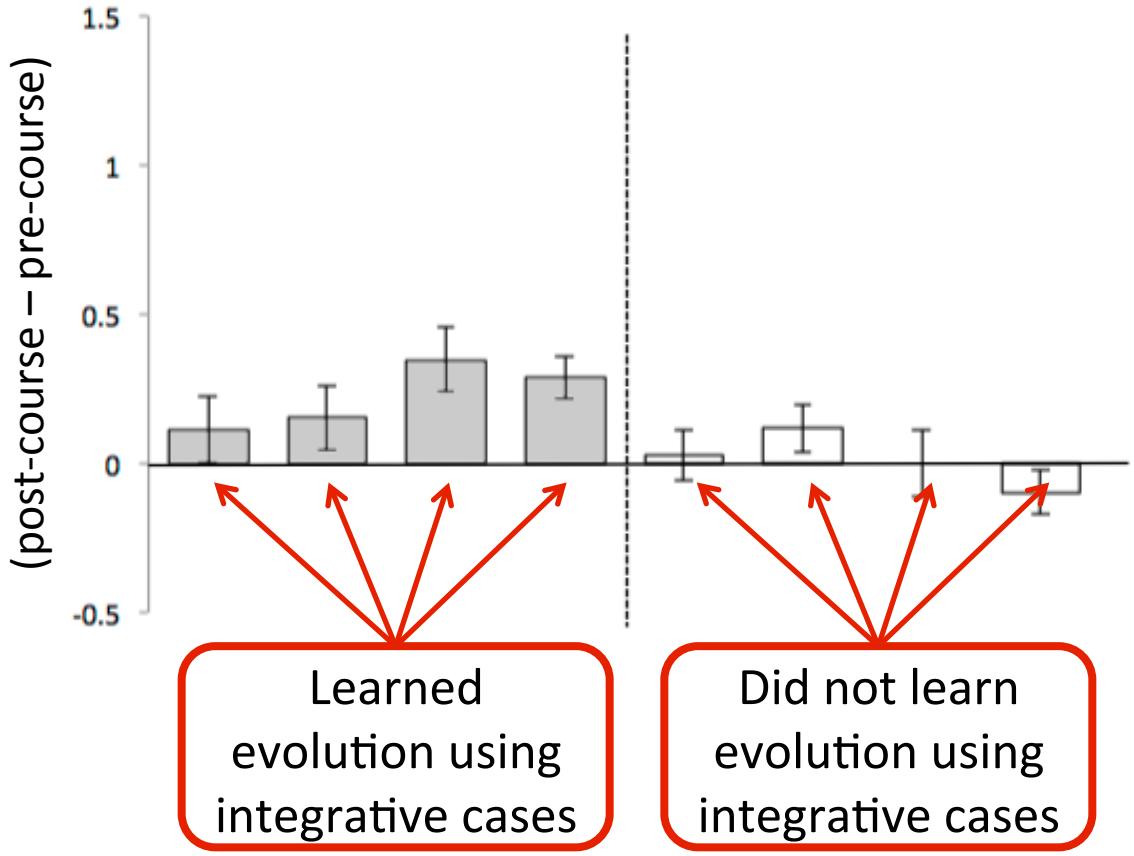


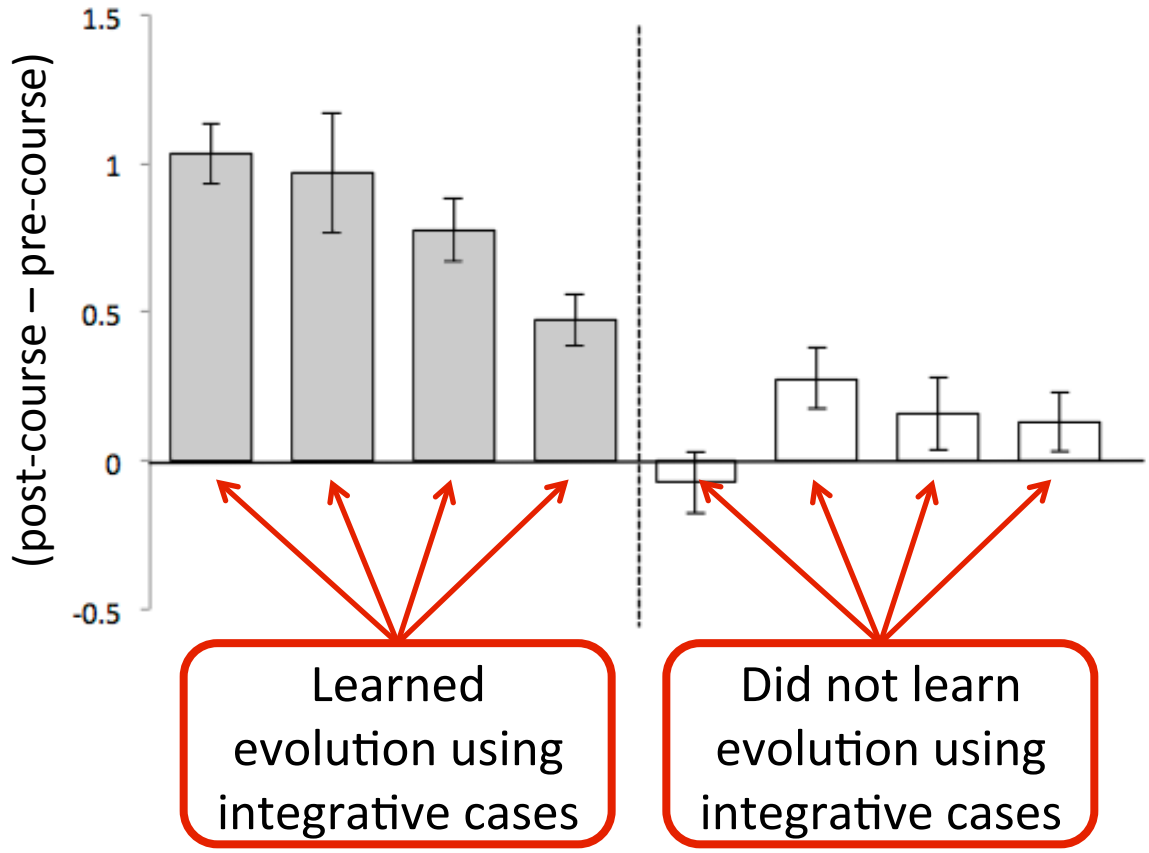
Q3: The non-poisonous Toxican mushroom has become more frequent in mushroom populations and poisonous Toxican mushrooms have become rare.

Define Natural Selection and use it to explain this scenario.

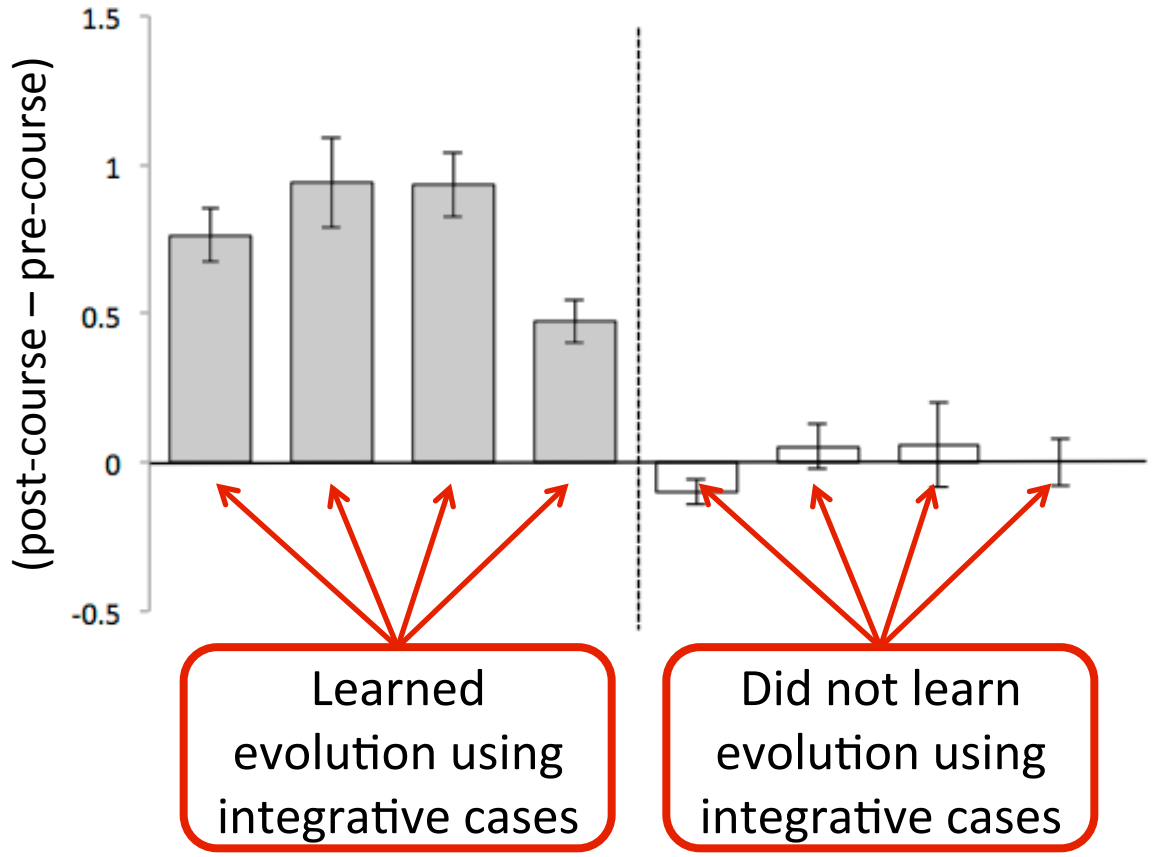


Q4i: Considering genetic mutation –

Describe, at the molecular level, what a mutation is.



Q4ii: Use your answer from part (i) to describe the process whereby a mutation results in a change at the phenotype level.



Multiple Regression Analysis:

In a single course where…

Post-Course ATEEK =
Pre-Course ATEEK + Course Grade + **Case Knowledge**

Multiple Regression Analysis:

Post-Course ATEEK =
Pre-Course ATEEK + Course Grade + Case Knowledge

Variable	Standard Coefficient	Standard Error	t-value	p-value
Pre-Course ATEEK	0.37	0.12	3.4	0.0013
Course Grade	0.11	0.054	0.82	0.42
Case Knowledge	0.36	0.13	2.8	0.0077

($F_{3,55} = 13.76$, Adjusted $R^2 = 0.40$)

Multiple Regression Analysis:

Post-Course ATEEK =
Pre-Course ATEEK + Course Grade + Case Knowledge

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Resources

Evo-Ed: Case Studies for Effective Evolution Education

www.evo-ed.com

Reader

Lyman Briggs Apps | LB145 S13 Homepage | LB492 S13 Homepage | MSU Netfiles | Evo-Ed: Cas...n Education

EVO ED

Cases for Evolution Education

Monkey Opsins | Mouse Fur Color | Pea Taste | Clam Toxin | Games and Sims

A complete understanding of evolution requires knowledge that spans many biological sub-disciplines. However, students are often taught evolution in the context of ecological systems and isolated from genetic and cellular ones. To address this issue, we have developed case studies that track the evolution of traits from their origination in DNA mutation, to the production of different proteins, to the fixation of alternate macroscopic phenotypes in reproductively isolated populations.

You can navigate through the case studies using the menu at the top of the page.

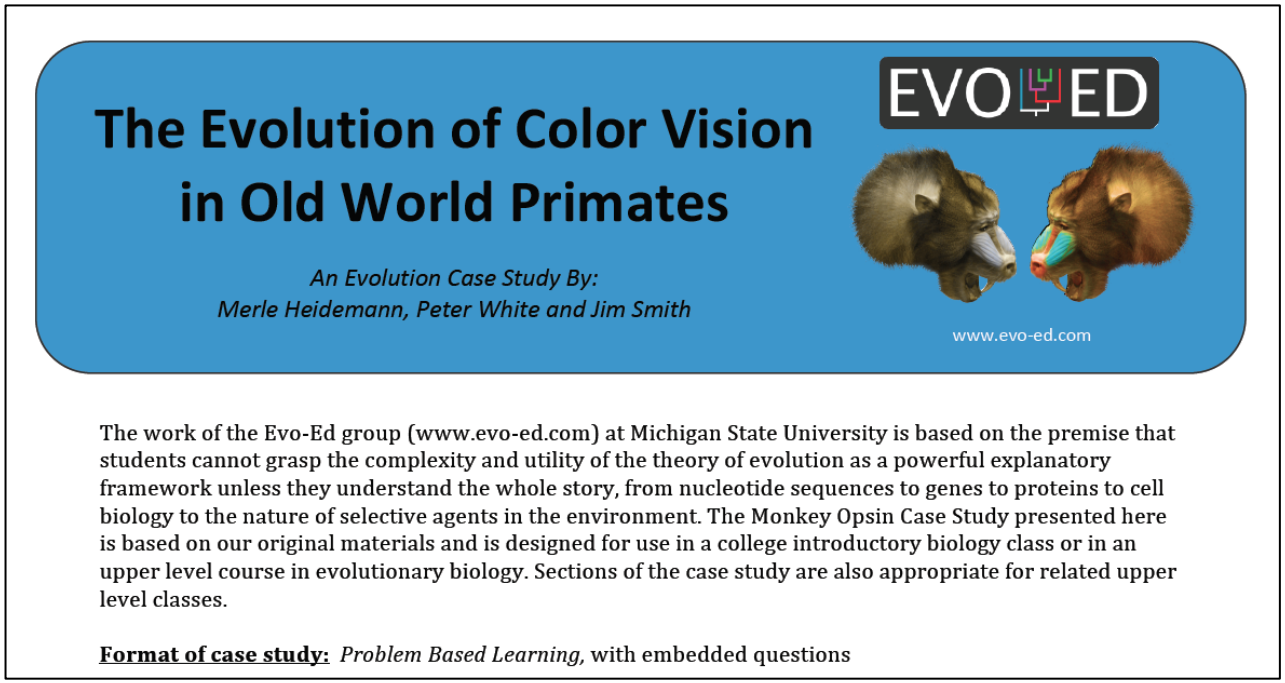
A short abstract of each case study is provided below with links to PowerPoint slides that are designed to be teaching resources for those who wish to implement one or more studies into their teaching.

"What does a Case look like?"

www.evo-ed.com

Resources

Case Study:



The Evolution of Color Vision in Old World Primates

An Evolution Case Study By:
Merle Heidemann, Peter White and Jim Smith

EVO ED

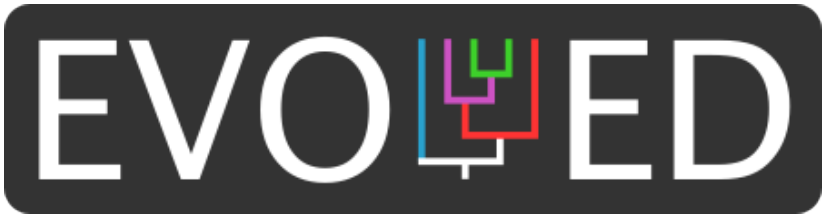
www.evo-ed.com

The work of the Evo-Ed group (www.evo-ed.com) at Michigan State University is based on the premise that students cannot grasp the complexity and utility of the theory of evolution as a powerful explanatory framework unless they understand the whole story, from nucleotide sequences to genes to proteins to cell biology to the nature of selective agents in the environment. The Monkey Opsin Case Study presented here is based on our original materials and is designed for use in a college introductory biology class or in an upper level course in evolutionary biology. Sections of the case study are also appropriate for related upper level classes.

Format of case study: *Problem Based Learning,* with embedded questions

www.evo-ed.com/casestudies/primates.pdf

Questions/Discussion?



http://www.evo-ed.com

Acknowledgements:

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Thanks to Kathis Ellis, Joe Murray, Miles Loh, Kendra Cheruvelil, Chuck Elzinga, Jerry Urquhart, Cheryl Murphy, Andy Jarosz, Doug Luckie, Craig Nelson, Mark Kauth and Lyman Briggs College for their contributions to the project.