Three-Dimensional Learning from Molecules to Populations

Louise S. Mead and Alexa R. Warwick
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CREATE for STEM Work-in-Progress Seminar
Project Team

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Outline

Introduction to the Connected Bio Project
- Project goals
- Curriculum framework & development process

Integrating across Levels
- Deer mice example
- Demo of interactives
- Student data

Next Steps
- Plan for research in Spring 2019
- Questions for discussion
Evolution is important...

Evolutionary processes explain the diversity of life on the planet, and research in this field continues to shed light on everything from the microbiome in your body to the ancestors that made you who you are.

Evolution education

All the current reforms place evolution as important… however

- Evolution is often taught as an isolated topic

INSTEAD:

Evolution should connect biological concepts across the curriculum
Genotype $\rightarrow$ Phenotype

gencode
RNA
Protein
Pathway
Trait phenotype
Genotype → Phenotype → Evolution
Evolution education

- Evolution key concepts: variation, heritability, selection
- Threshold concepts: randomness, probability, spatial scales, temporal scales

(Tibell and Harms 2017)
Project Background
ConnectedBio Project

By combining:

(a) The **integrative cases of trait evolution** developed by Evo-Ed/MSU

(b) The **interactive online learning simulations** of the Concord Consortium

(c) The **intentional design of curriculum for NGSS**
By combining:

(a) The integrative cases of trait evolution developed by Evo-Ed/MSU
(b) The interactive online learning simulations of the Concord Consortium
(c) The intentional design of curriculum for NGSS
We can investigate how students’:

1) ... learning develops over time when they experience a set of coherent interactive 3D biology learning materials.

2) ... understanding about the relationships between levels of biological organization (i.e. molecules, cells, organisms, and populations) develops and transfers from one biological phenomenon to another.
Driven by Phenomena

1. Experience Phenomenon
2. Raise Questions
3. Investigate using Three Dimensions
4. Develop Explanations, Artifacts, Raise New Questions
<table>
<thead>
<tr>
<th>Cases</th>
<th>Dark &amp; light fur</th>
<th>Sensitive &amp; resistant to neurotoxin</th>
<th>Smooth &amp; wrinkled shape</th>
<th>Dichromatic &amp; trichromatic vision</th>
<th>Persistence &amp; intolerance</th>
<th>Cit+ &amp; Cit-</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peromyscus polionotus</strong></td>
<td><strong>Mya arenaria</strong></td>
<td><strong>Pisum sativum</strong></td>
<td><strong>Across primate species</strong></td>
<td><strong>Homo sapiens</strong></td>
<td><strong>E. coli</strong></td>
<td></td>
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<tr>
<td>Eukaryotic</td>
<td>Eukaryotic</td>
<td>Eukaryotic</td>
<td>Eukaryotic</td>
<td>Eukaryotic</td>
<td>Prokaryotic</td>
<td></td>
</tr>
<tr>
<td>Natural selection</td>
<td>Natural selection</td>
<td>Artificial selection</td>
<td>Natural selection</td>
<td>Natural selection</td>
<td>Natural selection</td>
<td></td>
</tr>
<tr>
<td>Point mutation</td>
<td>Point mutation</td>
<td>~800 nucleotide insertion</td>
<td><strong>Gene duplication &amp; point mutation</strong></td>
<td>Mutation in control region</td>
<td>Duplication leading to novel gene regulation</td>
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Case Similarities & Differences

- Dark & light fur
- Sensitive & resistant to neurotoxin
- Smooth & wrinkled shape
- Dichromatic & trichromatic vision
- Persistence & intolerance

- Natural & Artificial selection
- Eukaryotic & Prokaryotic

- Peromyscus polionotus
- Mya arenaria
- Pisum sativum

- Across primate species
- Homo sapiens
- E. coli

- Point mutation
- ~800 nucleotide insertion
- Gene duplication + point mutation
- Mutation in control region

- Duplication leading to novel gene regulation

- TWO PHENOTYPES
  - SINGLE SPECIES
  - MULTIPLE SPECIES

- SINGLE SPECIES
- MULTICELLULAR
- NATURAL

- SINGLE SPECIES
- MULTICELLULAR
- NATURAL

- SINGLE MUTATION
- MULTIPLE MUTATIONS

- SINGLE MUTATION
- SINGLE CELL
3D Curriculum Development Process

**Identify**
- Phenomena
- Driving questions
- Investigations

**Specify NGSS Connections**
- DCIs
- Practices
- Cross-cutting concepts

**Integrate**
- Multi-Level Simulation (MLS)
- Embedded assessments

**Content**

**Case Synopsis/Process Figures**

**Teacher and Student Feedback**

**Unit/Lesson Guides**

**Technology**

**Teacher Collaborators**
Account for spatial scale

- Multiple levels of biological organization

<p>| population | organism | trait | cells | proteins | DNA |</p>
<table>
<thead>
<tr>
<th>Level</th>
<th>Population(s)</th>
<th>Organism</th>
<th>Trait</th>
<th>Cell</th>
<th>Protein</th>
<th>DNA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Field/Beach</td>
<td>Mouse</td>
<td>Proportion of light colored mice increases in frequency in populations living on/near beaches</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Experience differential survival and reproduction based on inherited traits</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Is genetically determined by alleles inherited from parents</td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Can produce differing amounts of eumelanin and pheomelanin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Binds alpha-MSH and initiates melanin synthesis</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Goes through the process of replication and accumulates mutations</td>
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### Integrating across levels:

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<th>Level</th>
<th>Cell</th>
<th>Protein</th>
<th>DNA</th>
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<tr>
<td></td>
<td>Melanocyte</td>
<td>MC1R</td>
<td>MC1R Gene</td>
</tr>
<tr>
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<td>Population</td>
<td>Comprised of individuals living in a particular environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Differences in heritable traits among individuals can impact survival and reproduction that changes the distribution of traits in the population</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Demos

Unit 1. Lesson 1.1 Natural History of Deer Mice
https://authoring.concord.org/activities/9005

Unit 1. Lesson 1.2 Ecology Deer Mice
https://authoring.concord.org/activities/9006

Unit 2. Lesson 2.1 Cell Biology of Deer Mice
https://authoring.concord.org/activities/9083

Unit 2. Lesson 2.2 Molecular Biology of Deer Mice
https://authoring.concord.org/activities/9076/
UI/UX will allow students to move from level to level
Outline

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What explanations do students have about the case content and evolution? *(prior to case instruction)*
Fall 2017 - Spring 2018: Implementation and Research Goals

1. Identify which cases teachers use in their classroom. Collate materials used.
2. Design ConnectedBio curriculum (initially all cases → deer mouse case)
3. Describe what initial conceptions students have (case content & evolution).

Research Questions

1. What prior knowledge do high school biology students use when explaining evolutionary case phenomena? (specific case context and evo concepts)
2. How often do high school biology students make connections across biological levels in their explanations?
3. What kinds of connections do high school biology students make when responding to scaffolded and unscaffolded questions about evolutionary phenomena?
Student Prior Knowledge

• Four sets of open-ended survey questions
  1. Mouse fur color case (multiple questions)
  2. Clam toxin resistance case (multiple questions)
  3. Monkey vision case (multiple questions – phylogenies)
  4. Multi-case (one question from each case)

• Each teacher gave out 1, 2, or 3 surveys to their students in 2017-2018
• Evaluating/coding written responses
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• Each teacher gave out 1, 2, or 3 surveys to their students in 2017-2018

• Evaluating/coding written responses
  1. Common alternative conceptions to the case context – what explanations do students have?
  2. Evolution key concepts – scientific (i.e. variation, heritability, etc.) vs. naïve (i.e. need, use, etc.)
     (used in Nehm et al. 2012)
  3. Threshold concepts (randomness, probability, spatial and temporal scales) (Tibell & Harms 2017)
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• Each teacher gave out 1, 2, or 3 surveys to their students in 2017-2018
• Evaluating/coding written responses
• Followed up with some students via interview
• Today – preliminary results for two teachers and the deer mouse case
1. Most mice in dark soil fields have dark fur and most mice on light sandy beaches have light fur. Why might these fur colors be associated with these habitats?
Student Survey: Mouse Fur Color

1. Most mice in dark soil fields have dark fur and most mice on light sandy beaches have light fur. Why might these fur colors be associated with these habitats?

2. How would you explain the differences in fur color at the molecular level (in terms of DNA and/or proteins)?

3. How would you explain the differences in fur color at the cellular level?

Jen (14 years experience): 54 9th grade general biology students
Mark (26 years experience): 42 11th/12th grade AP biology students
<table>
<thead>
<tr>
<th>Explanation</th>
<th>% Students (9th / AP)</th>
<th>Example Student Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camouflage</td>
<td>81% / 86%</td>
<td>“To blend in with their surroundings so predators can't see them and the mice won't die”</td>
</tr>
<tr>
<td>Bleaching</td>
<td>11% / 0%</td>
<td>“because the mice in the beaches are in the sun all the time so their fur becomes lighter and the dark fur mice are always shaded because they are in a field”</td>
</tr>
<tr>
<td>Heat</td>
<td>7% / 0%</td>
<td>“the mice try to blend in with their surroundings also because the mice in a dark field most likely need fur that will attract heat while on the beach mice have light fur so they can be in the sun without overheating”</td>
</tr>
<tr>
<td>Dirty</td>
<td>5% / 0%</td>
<td>“The dark soil may rub off on the mice giving them darker fur. But also it may be genetic…”</td>
</tr>
<tr>
<td>Other</td>
<td>11% / 0%</td>
<td>“I think the mice have adapted to their environment, to blend in and keep away from predators. Like that one kind of weasel that changes color in the winter…”</td>
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<td>7% / 0%</td>
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<td>Evolution Key Concept</td>
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<td>Variation (mutation)</td>
<td>4% / 10%</td>
<td>&quot;...The change in coloring may have been due to a certain mutation, or certain genes that have been turned on or off.&quot;</td>
</tr>
<tr>
<td>Inheritance</td>
<td>0% / 10%</td>
<td>&quot;These colors of fur are associated with their respective habitats because mice with these fur colors would have a better chance of survival, and are able to have more offspring to pass down the trait.&quot;</td>
</tr>
<tr>
<td>Differential survival and/or reproduction (Selection)</td>
<td>9% / 31%</td>
<td>&quot;Mice with dark fur can better blend in with the dark soil and mice with light fur can blend in with the light sand. This way it is more difficult for predators to hunt them. Natural selection causes the mice with the better fur for their environment to be able to survive and produce offspring.&quot;</td>
</tr>
<tr>
<td>Change in population trait distribution</td>
<td>0% / 5%</td>
<td>&quot;...If at one point there was a time with dark and light fur mice on a dark soil then due to natural selection the light furred mice would be eaten by predators meaning more dark fur would be in the gene pool producing more dark furred mice in an environment similar to their color.&quot;</td>
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2. How would you explain the differences in fur color at the **molecular** level (in terms of DNA and/or proteins)?

3. How would you explain the differences in fur color at the **cellular** level?
Student Prior Knowledge: Connecting Levels

- Attempted connections:
  - Referenced at least two levels in their response.
  - 37% of Jen’s 9th grade students, 67% of Marks’ 11th/12th grade students
  - Example from Mark’s class: “one letter of the DNA sequence is replaced by another letter accidentally, and thus creates a different fur color.”

- Students referenced DNA/genetics, proteins, or cells, but Mark’s students had more detailed explanations, used scientific terms (nucleotide sequences, chromosomes, dominance)
Student Prior Knowledge Summary

• 9th and AP students both had the same most common explanation for the mouse fur color case (camouflage)

• None of the AP students proposed alternative explanations, but used more evolution key concepts

• Both groups of students made limited connections across levels in question 1

• Both groups of students do better at making connections with scaffolded questions (2 and 3)

• Difficult to code some alternative explanations using molecular and cellular levels (i.e. dirty - not an evolutionary explanation)
Next Steps for Initial Student Surveys

- Continuing to evaluate/code written responses for mice and clams
- Evaluating student thinking revealed by follow-up interviews (terminology)
- Using these results to develop the ConnectedBio curriculum
Project Next Steps
We can investigate how students’:

1) ... learning develops over time when they experience a set of coherent interactive 3D biology learning materials.

2) ... understanding about the relationships between levels of biological organization (i.e. molecules, cells, organisms, and populations) develops and transfers from one biological phenomenon to another.
Project Timeline

2017
Use principles of 3D learning to design a coherent learning sequence

2018
Adapt a cyclical, case-based approach

2019
Develop supporting technology-based environments
Test materials in an agile, iterative manner

2020
Analyze the findings and disseminate
Measure student use of core ideas, crosscutting concepts and practices
Spring 2019: Implementation and Research Goals

1. Identify areas of difficulty for students and teachers
2. Iteratively update the Deer Mouse case lessons and teacher guides
3. Describe how students work through the case materials

Research Questions

1. How do students engage with our three-dimensional materials?
   a. What does their discourse look like?
2. How do students make connections across levels throughout the case?
   a. What do their models look like?
Data Collection

5 Teachers
- Daily log
- Interviews

3 Student Groups of 3-4 Each
- Artifacts (models)
- Written responses within lessons
- Simulation use log data
- Audio (or video?) recordings
- Interviews
Data Collection

- Iteratively update materials based on prior implementations (inform goals 1, 2)
- Piloting of interview protocols using these teachers and their students

- Finalize curriculum to serve as a case study (goal 3)
- Focus on one (or two) student groups per teacher
3D Curriculum Development Process

**CONTENT**

**IDENTIFY**
- Phenomena
- Driving questions
- Investigations

**SPECIFY NGSS CONNECTIONS**
- DCIs
- Practices
- Cross cutting concepts

**TEACHER AND STUDENT FEEDBACK**

**UNIT/LESSON GUIDES**

**TECHNOLOGY**
- Multi-Level Simulation (MLS)
- Embedded assessments

**INTEGRATE**

**CASE SYNOPSIS/PROCESS FIGURES**

**TEACHER COLLABORATORS**
Discussion Questions

- **Integrating across levels:** What other ways could we evaluate whether students are making connections between levels? How can we scaffold a question that assesses students ability to make connections across levels?

- **Research plan:** Is our plan for research in Spring 2019 sufficient to address our questions? What should 3D assessment of 3D curriculum look like?

- **Next case:** We plan to develop at least one more case. Would it be better to develop a case with a phenomenon similar to deer mice for evaluating knowledge transfer or one that is more complementary (phenomenon is less similar to deer mice)?
Case Similarities & Differences

- Dark & light fur
- Sensitive & resistant to neurotoxin
- Smooth & wrinkled shape
- Dichromatic & trichromatic vision
- Persistence & intolerance
- Natural selection & artificial selection
- Eukaryotic & prokaryotic
- Peromyscus polionotus & Mya arenaria
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- Point mutation
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- Mutation in control region
- Duplication leading to novel gene regulation

- Two phenotypes
- Single species
- Multicellular
- Natural
- Single mutation
- Multiple mutations
- Single species
- Single cell
- Natural
- Artificial
- Single mutation
- Multiple species
- Multicellular
- Natural
Clam toxin resistance

• A toxin is present in the ocean where a population of Sand Gaper clams live. All individuals in the population are exposed to the toxin. Some of these individuals, however, are negatively affected and die or become paralyzed. Other individuals in the population are unaffected. **Explain why some individuals are affected by the toxin while others are not.**
Clam toxin resistance

• **Mutation**
• **Distance** from the area changes level of exposure
• **Cells** = ? couldn’t get into the cells completely
• **Concentration** difference as it spread
• **Immune** system protects from the toxin
• **General strength/health** of the clam prior to exposure, including age and size
E. coli citrate case

• PROMPT: Scientists are growing populations of the same bacteria in 12 different containers in the lab, with one population per container. All of the populations are provided with a food source they can use (glucose) and a food source they generally cannot use (citrate). After many generations (years) the scientists noticed the bacteria in one population (Container 9) were growing more than the others. Explain why might the bacteria in Container 9 grow more than the bacteria in the other containers (1-8 and 10-12)?

• 9th Grade Biology
E. coli citrate case

• Out of 42 students, 38 had responses and 36 of these were coded (2 were too vague to code)

• 14 had some mention of genetics

  “One population of bacteria (Container 9) grows more because the bacteria was genetically lined up to match and grow more and had different modifications.” [#9]

  “One population of bacteria (Container 9) grows more because they can eat the other bacteria.” [#34]

• 30 mentioned the food source
  • 7 wrote that bacteria were eating other bacteria in order to grow more
  • 17 referenced using citrate (only 5 said using both citrate and glucose)

• 8 had other explanations

  “One population of bacteria (Container 9) grows more because they adapted to eat the citrate, which made the bacteria less limited in how much they could grow compared to the other containers, as they had two food sourced instead of only one.” [#1]