Promoting 21st Century Learning with Model-based Instruction

KBS K12 Partnership, October 5, 2011
Tammy M. Long, Michigan State University
What is the state of 21st Century biology teaching and learning?
Literature: 25 Years of Calls for Reform
Conclusion:

“Traditional” model of introductory biology isn’t preparing students for the “new” biology.

“Realizing that the status quo in science education is not achieving the results we need, we have to undertake this bold challenge ...”

- Arden Bement, Former Director, National Science Foundation

In, Vision and Change In Undergraduate Biology Education: A Call to Action. 2009. American Association for the Advancement of Science.
What is the “new” biology?

- How is the science of biology changing?
## Changing nature of biology: volume

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<th>Text</th>
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<td>Biology, 8(^{th}) ed. Campbell et al.</td>
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<td>Biological Science, 2(^{nd}) ed. Freeman et al.</td>
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<td>Life, 9(^{th}) ed. Sadava et al.</td>
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number of chromosomes yet again. This does not happen, however, because in sexually reproducing organisms, the gametes are formed by a modified type of cell division called meiosis. This type of cell division reduces the number of sets of chromosomes from two to one in the gametes, counterbalancing the doubling that occurs at fertilization. In animals, meiosis occurs only in the ovaries or testes. As a result of meiosis, each human sperm and egg is haploid (n = 23). Fertilization restores the diploid condition by combining two haploid sets of chromosomes, and the human life cycle is repeated, generation after generation (see Figure 13.5). You will learn more about the production of sperm and eggs in Chapter 46.

In general, the steps of the human life cycle are typical of many sexually reproducing animals. Indeed, the processes of fertilization and meiosis are the unique trademarks of sexual reproduction, in plants as well as animals. Fertilization and meiosis alternate in sexual life cycles, maintaining a constant number of chromosomes in each species from one generation to the next.

The Variety of Sexual Life Cycles

Although the alternation of meiosis and fertilization is common to all organisms that reproduce sexually, the timing of these two events in the life cycle varies, depending on the species. These variations can be grouped into three main types of life cycles. In the type that occurs in humans and most other animals, the only haploid cells are the gametes. Meiosis occurs in germ undergo no fertilization, a multicellular organism.

Plants and some species of algae exhibit a second type of life cycle called alternation of generations. This type includes both diploid and haploid stages that are multicellular. The multicellular diploid stage is called the sporophyte. Meiosis in the sporophyte produces haploid cells called spores. Unlike a gamete, a haploid spore doesn’t fuse with another cell but divides mitotically, generating a multicellular haploid stage called the gametophyte. Cells of the gametophyte give rise to gametes by mitosis. Fusion of two haploid gametes at fertilization results in a diploid zygote, which develops into the next sporophyte generation. Therefore, in this type of life cycle, the sporophyte generation produces a gametophyte as its offspring, and the gametophyte generation produces the next sporophyte generation (Figure 13.6b). Clearly, the term alternation of generations is a fitting name for this type of life cycle.

A third type of life cycle occurs in many fungi and some protists, including some algae. After gametes fuse and form a diploid zygote, meiosis occurs without a multicellular diploid offspring developing. Meiosis produces not gametes but haploid cells that then divide by mitosis and rise to either unicellular descendants or a haploid multicellular adult organism. Subsequently, the haploid organism carries out further mitoses, producing the cells that develop into gametes. The only diploid stage found in these species is the single-celled zygote (Figure 13.6c).

Note that either haploid or diploid cells can divide by mitosis depending on the type of life cycle. Only haploid cells can

Key
- Haploid (n)
- Diploid (2n)

(a) Animals
(b) Plants and some algae
(c) Most fungi and some protists

Figure 13.6 Three types of sexual life cycles. The common feature of all three cycles is the alternation of meiosis and fertilization; key events that contribute to genetic variation among offspring. The cycles differ in the timing of these two key events.

Compartmentalization, linearity

Exploring The Meiotic Division of an Animal Cell

MEIOSIS I: Separates homologous chromosomes

Prophase I
- Chromosomes begin to condense, and homologous loosely pair along their lengths, aligned gene by gene.
- Crossing over (the exchange of corresponding segments of DNA molecules by nonister chromatids) is completed while homologues are in synapsis, held tightly together by proteins along their lengths (before the stage shown).
- Synapsis ends in mid-prophase, and the chromosomes in each pair move apart slightly, as shown above.
- Each homologous pair has one or more chiasmata, points where crossing over has occurred and the homologs are still associated due to cohesion between sister chromatids (sister chromatid cohesion).

Centromere movement, spindle formation, and nuclear envelope breakdown occur as in mitosis.
- In late prophase (after the stage shown), microtubules from one pole or the other attach to the two kinetochores, protein structures at the centromeres of the two homologs. The homologous pairs then move toward the metaphase plate.

Anaphase I
- Breakdown of proteins responsible for sister chromatid cohesion allows homologs to separate.
- The homologs move toward opposite poles, guided by the spindles.
- Sister chromatid cohesion persists at the centromere, causing chromatids to move as a unit toward the same pole.

Metaphase I
- Pairs of homologous chromosomes are now arranged on the metaphase plate, with one chromosome in each pair facing each pole.
- Both chromatids of one homolog are attached to kinetochore microtubules from one pole; those of the other homolog are attached to microtubules from the opposite pole.

Telophase I and Cytokinesis
- At the beginning of telophase I, each half of the cell has a complete haploid set of replicated chromosomes. Each chromosome is composed of two sister chromatids; one or both chromatids include regions of nonister chromatid DNA.
- Cytokinesis (division of the cytoplasm) usually occurs simultaneously with telophase I, forming two haploid daughter cells.
- In animal cells, a cleavage furrow forms, the plant cells, a cell plate forms.
- In some species, chromosomes decondense and the nuclear envelope re-forms.
- No replication occurs between meiosis I and meiosis II.
Contemporary biology is the study of *systems*. 
Systems Thinking Skills:

- Identify system components and processes
- Organize into a meaningful framework, based on system interactions
- Understand dynamic nature of interactions that traverse scales (space, time)
- Identify and predict system feedbacks, cycles, and emergent properties

(Pennisi 2003; Ben-Zvi Assaraf & Orion 2005; Stave & Hopper 2007)
Preparing students for systems thinking?
Introductory Biology Reform at MSU

**Project Objective:** Design, implement and evaluate the impacts of introductory biology reform.
How do we (most university faculty) design a course?
Backward Design

Goals

What should students know, be able to do?

Assessment

What evidence will we accept?

Instruction

How can we best prepare students?

Adapted from Wiggins and McTighe (1998)
## Goals for Intro Bio

### Literature
- **Nature of science**  
  - Construct, interpret, evaluate, apply, and communicate scientific information (i.e., data, models, arguments, evidence)

### Program
- **Prepare students for upper-division coursework**  
  - Foundational knowledge in genetics, ecology, evolution

### Faculty
MSU Biology Faculty Feedback

- “About 95% of the students I get can memorize information, but they can’t do anything with it - like apply it to a real problem.”
- “[Students] don’t seem able to make connections among concepts; they don’t see how you can transfer a basic principle to a new situation.”
- “Students are willing to believe anything they find on the web – it appears they don’t critically evaluate the information they are exposed to.”
- “I think our majors should be able to read the Science section of the New York Times and be able to explain it to their grandmother.”
MSU Faculty Feedback (n=10)

- Motivation
- Recall
- Science process
- Evaluate info
- Models, representations
- Apply, connect, transfer
Goals for Intro Bio

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<thead>
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<th>Literature</th>
<th>Program</th>
<th>Faculty</th>
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</table>
| • Nature of science  
- Construct, interpret, evaluate, apply, and communicate scientific information (i.e., data, models, arguments, evidence) | • Prepare students for upper-division coursework  
- Foundational knowledge in genetics, ecology, evolution | • Apply concepts  
• Make connections  
• Transfer principles |
Backward Design

Goals

What should students know, be able to do?

Assessment

What evidence will we accept?

Instruction

How can we best prepare students?

Adapted from Wiggins and McTighe (1998)
Tools of Science

Data
- Collect
- Graph
- Interpret
- Analyze
- Evaluate

Models

Arguments
- Claim
- Evidence
- Warrant
- The trees in section one that are smaller grow taller so that they can compete with the larger tree for sunlight. When this happened, the short-necked animals weren't able to eat as well as the dino with a long neck. The idea is that in box two, the long-necked dino survives because it is able to obtain food better. It is able to reproduce because it doesn't die, and is fit and strong to live. The dino produces offspring with the trait and gradually over time, offspring with longer necks are more fit to eat and survive to produce offspring. Thus, in box 3, the long-necked dinos are present.
System Model

- Inspired by Structure-Behavior-Function Theory (SBF; Goel 1996).
Structures

- Structure 1
  - Behavior 1-2
  - Behavior 3-1

- Structure 2
  - Behavior 2-3
  - Behavior 2-4

- Structure 3

- Structure 4

System components (usually nouns)
Behaviors

system processes (usually verbs)
- describe relationships between pairs of structures.

Structure 1

Behavior 1-2

Structure 2

Behavior 1-2

Structure 3

Behavior 3-1

Structure 4

Behavior 2-4

Behavior 2-3
Function

Structure 1

Behavior 1-2

Structure 2

Behavior 2-3

Behavior 2-4

Structure 3

Behavior 3-1

Structure 4

output, role, purpose of a system

FuncMon output, role, purpose of a system
Simplifying Complexity: Analyzing Students’ Models of Biological Systems

- What concepts do students view as relevant to a system?
- How do students organize their thinking?
- How do student models change over time?
- Do students use models to formulate predictions and explanations?
- How do students evaluate models?
- Are student-constructed models accurate representations of their thinking?

NSF, REESE – Long, PI
Simplifying Complexity: Analyzing Students’ Models of Biological Systems

- What concepts do students view as relevant to a system?
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NSF, REESE – Long, PI
Goal: Develop students’ understanding of the connections among concepts in genetics, evolution, and ecology.
Early in semester:

Construct a systems model that shows relationships among the following concepts:

- Gene
- Chromosome
- DNA
### HBB Sequence in Normal Adult Hemoglobin (Hb A):

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<th>Nucleotide</th>
<th>CTG</th>
<th>ACT</th>
<th>CCT</th>
<th>GAG</th>
<th>GAG</th>
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<tr>
<td>Amino Acid</td>
<td>Leu</td>
<td>Thr</td>
<td>Pro</td>
<td>Glu</td>
<td>Glu</td>
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### HBB Sequence in Mutant Adult Hemoglobin (Hb S):

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Construct a systems model that shows relationships among the following concepts. A correct model must:

a) explain how genetic variation originates and is expressed;

b) illustrate the consequences of phenotypic variation on fitness within the population; and,

c) be context-specific for the case provided.

- Gene
- Chromosome
- Protein
- Nucleotide
- Phenotype
- DNA
- Allele
- Fitness
Quiz 2:

Final:
Change in Model Metrics Over Time

- Complexity
- Correctness

Performance

Early  Mid-semester  Late
Conclusions?

- All tritiles of students demonstrate improved understanding of concepts (correctness).
  - Greatest relative gain for lowest tritile

- Complexity increases through midterm, then decreases by final exam.
Conclusions:

- Modeling is consistent with reform goals and developing systems thinking skills
  → establishing connections among concepts

- Models are an authentic form of instruction and assessment – and practical alternative for large classes

- Models provide insight into student thinking
  - change over time
  - opportunity for instructional intervention
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