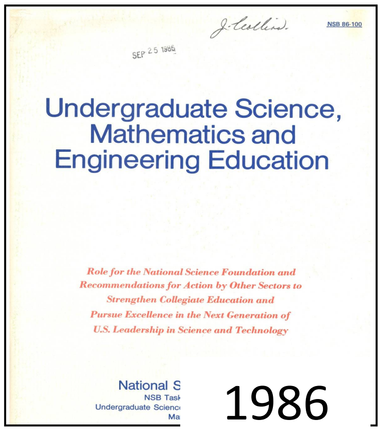
Promoting 21st Century Learning with Model-based Instruction

KBS K12 Partnership, October 5, 2011

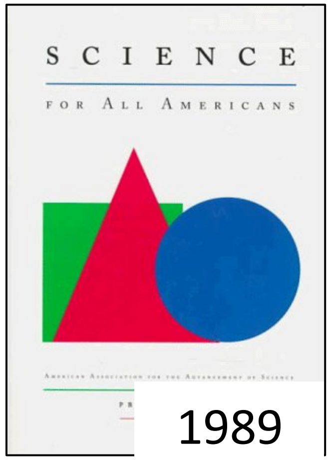
Tammy M. Long, Michigan State University

What is the state of 21st Century biology teaching and learning?

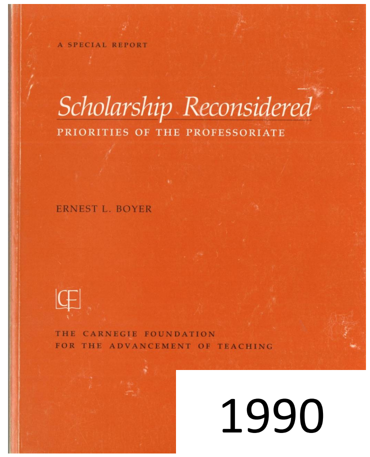
Literature: 25 Years of Calls for Reform



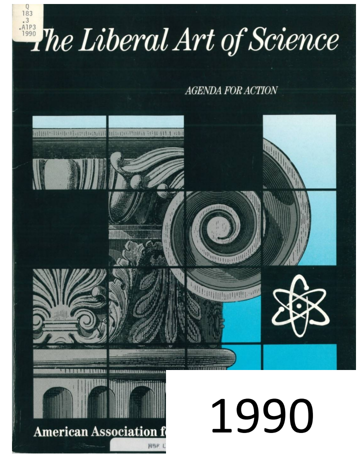
1986



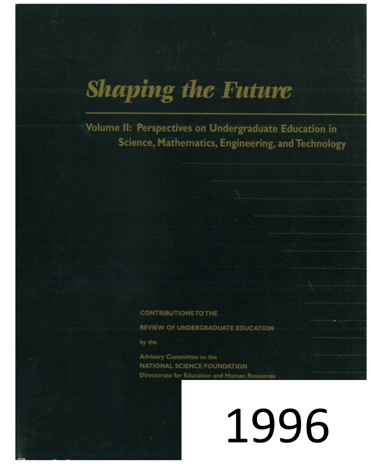
1989



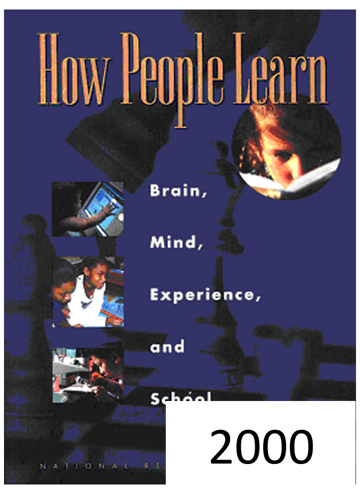
1990



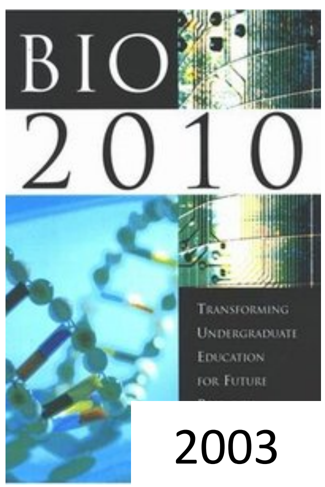
1990



1996

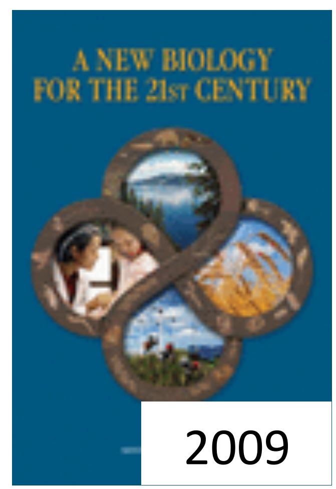


2000

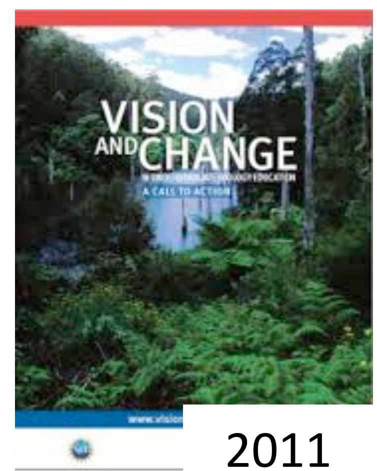


2003

2008



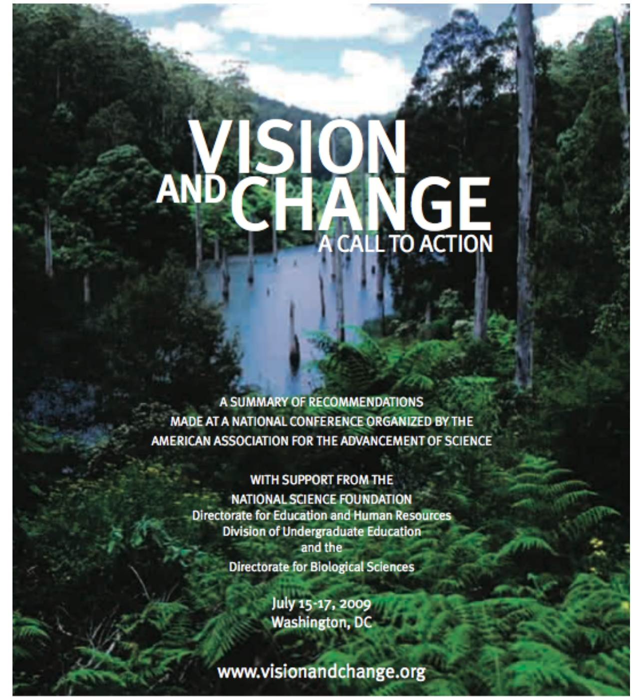
2009



2011

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

Text	Units	Chs	Pages
Biology, 8th ed. Campbell et al.	8	56	1267
Biological Science, 2nd ed. Freeman et al.	9	55	1283
Biology, The Dynamic Science Russell et al.	7	55	1289
Biology, 2nd ed. Brooker et al.	8	60	1282
Life, 9th ed. Sadava et al.	10	59	1259

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

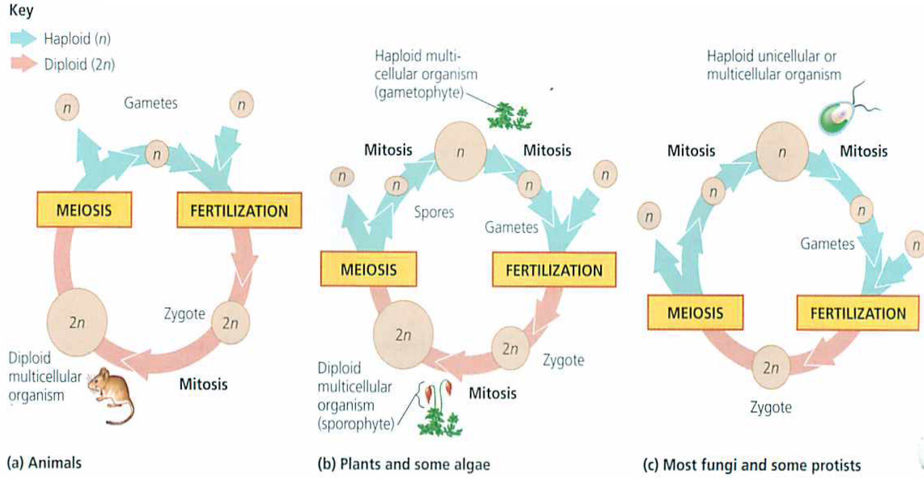
Although the alternation of meiosis and fertilization is common to all organisms that reproduce sexually, the timing of these two events in the life cycle varies, depending on the species. These variations can be grouped into three main types of life cycles. In the type that occurs in humans and most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

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 most 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 give 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 diploid cells, how...

Compartmentalization, linearity

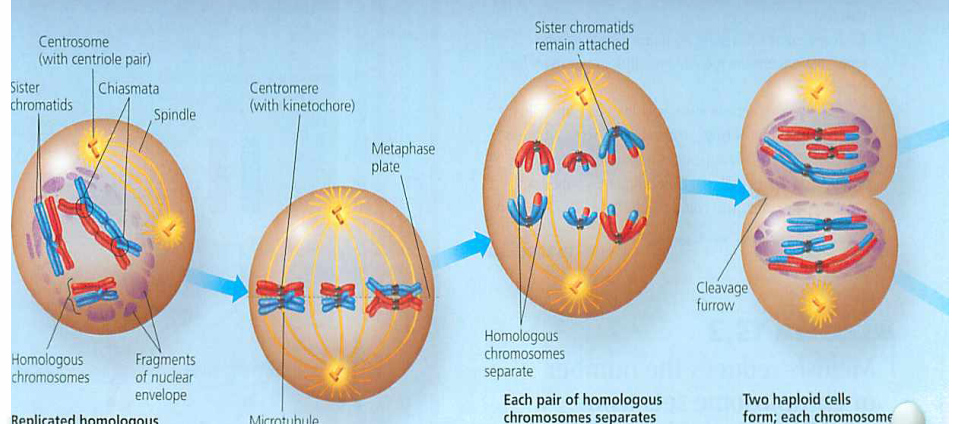


▲ **Figure 13.6 Three types of sexual life cycles.** The common feature of all three cycles is the alternation of meiosis and fertilization, key events that contribute to genetic variation among offspring. The cycles differ in the timing of these two key events.

▼ **Figure 13.8**

Exploring The Meiotic Division of an Animal Cell

MEIOSIS I: Separates homologous chromosomes



Prophase I

- Chromosomes begin to condense, and homologs loosely pair along their lengths, aligned gene by gene.
- Crossing over (the exchange of corresponding segments of DNA molecules by nonsister chromatids) is completed while homologs 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*).
- Centrosome movement, spindle formation, and nuclear envelope breakdown occur as in mitosis.
- In late prophase I (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.

Metaphase I

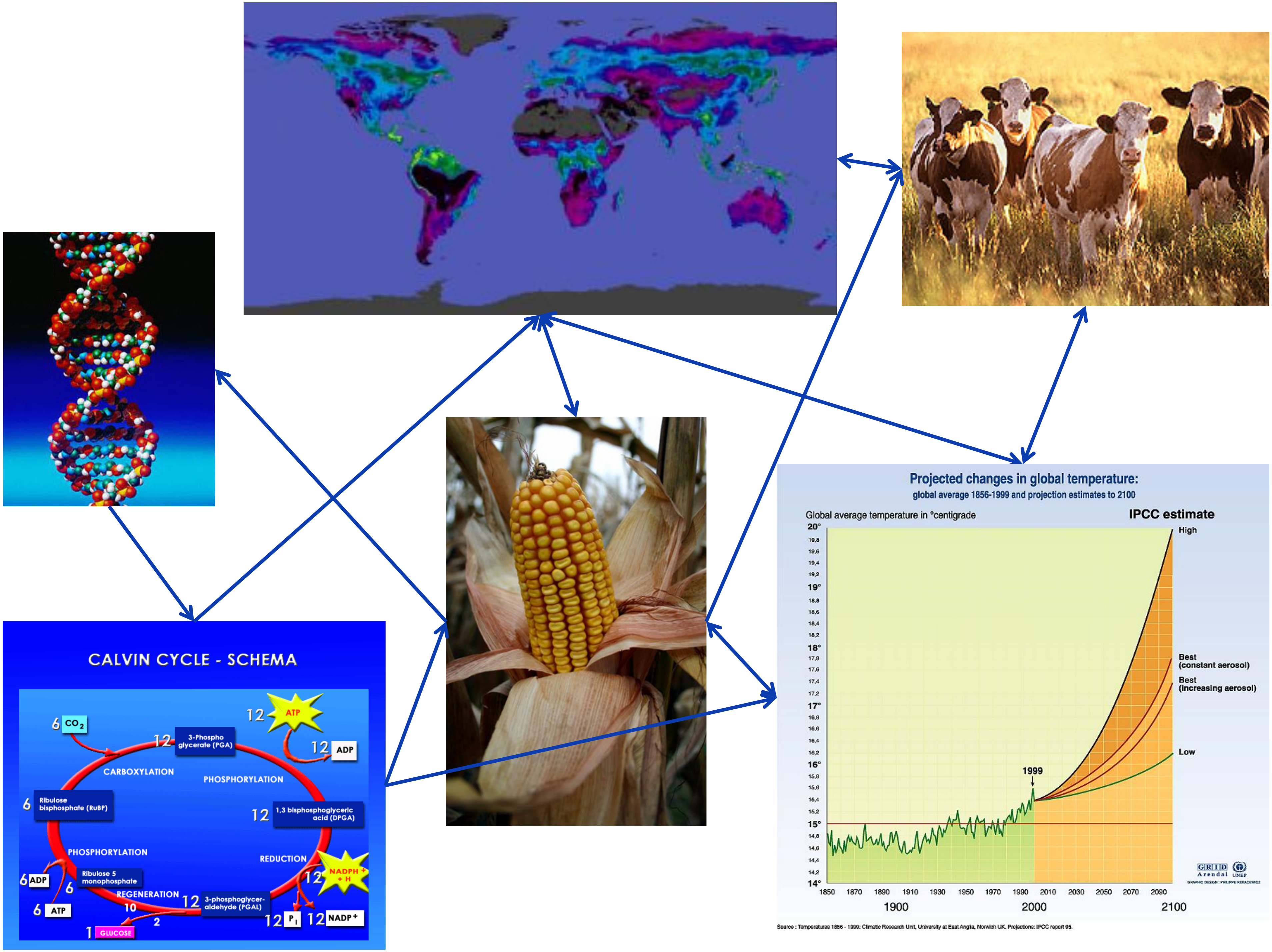
- Pairs of homologous chromosomes are now arranged on the metaphase plate, with one chromosome in each pair facing each pole.
- Both chromatids of one homolog are attached to kinetochore microtubules from one pole; those of the other homolog are attached to microtubules from the opposite pole.

Anaphase I

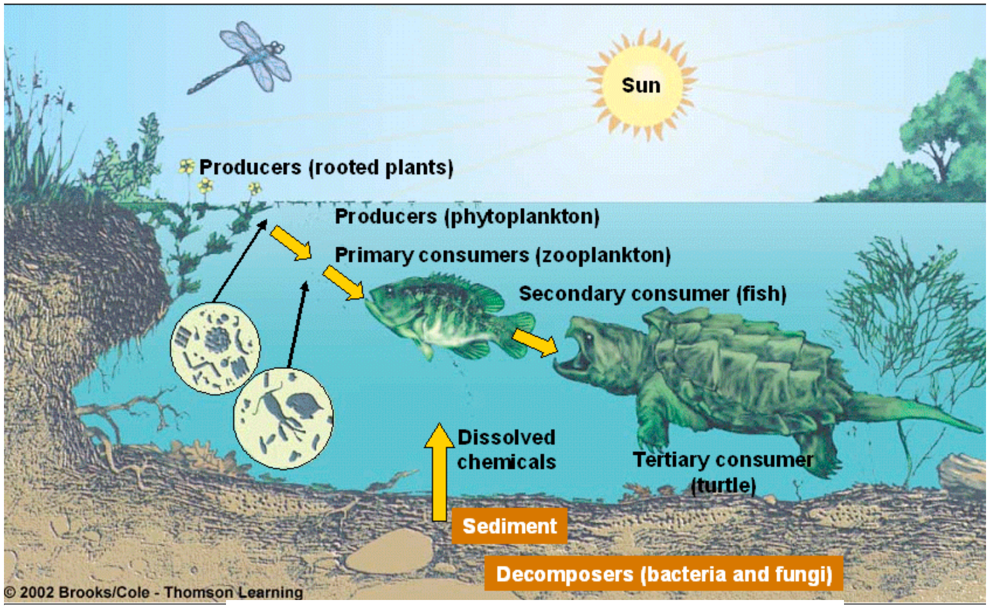
- Breakdown of proteins responsible for sister chromatid cohesion along chromatid arms allows homologs to separate.
- The homologs move toward opposite poles, guided by the spindle apparatus.
- Sister chromatid cohesion persists at the centromere, causing chromatids to move as a unit toward the same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

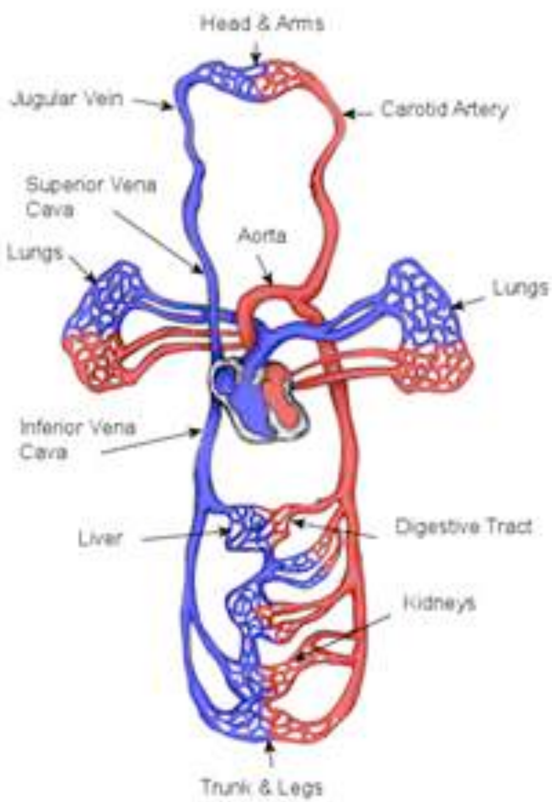
Telophase I and Cytokinesis

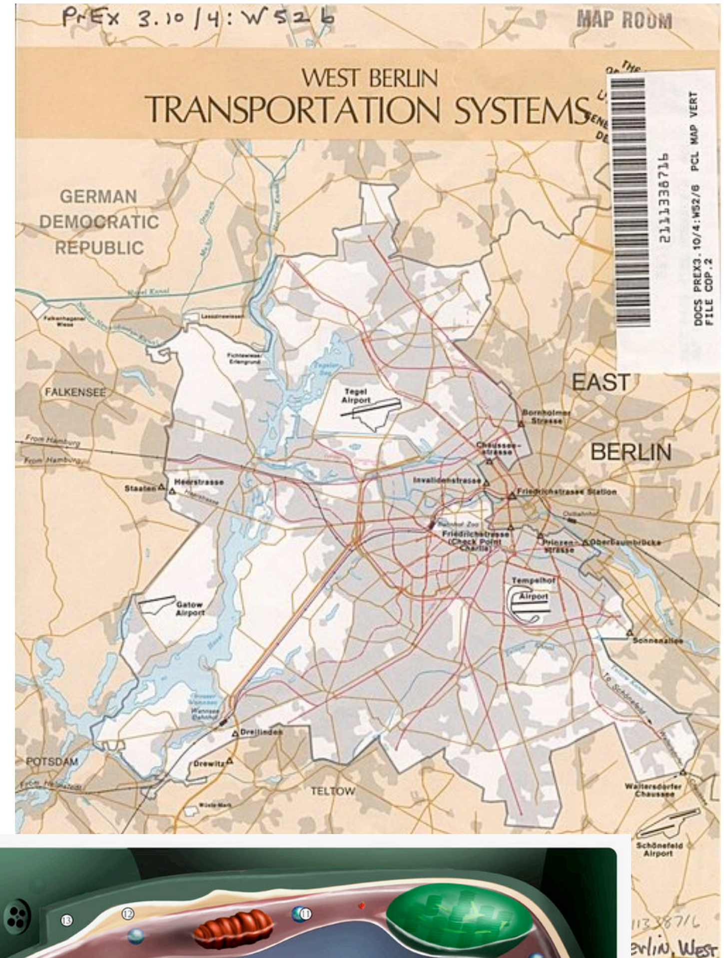
- At the beginning of telophase I, each half of the cell has a complete haploid set of replicated chromosomes. Each chromosome is composed of two sister chromatids; one or both chromatids include regions of nonsister chromatid DNA.
- Cytokinesis (division of the cytoplasm) usually occurs simultaneously with telophase I, forming two haploid daughter cells.
- In animal cells, a cleavage furrow forms. (In 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.

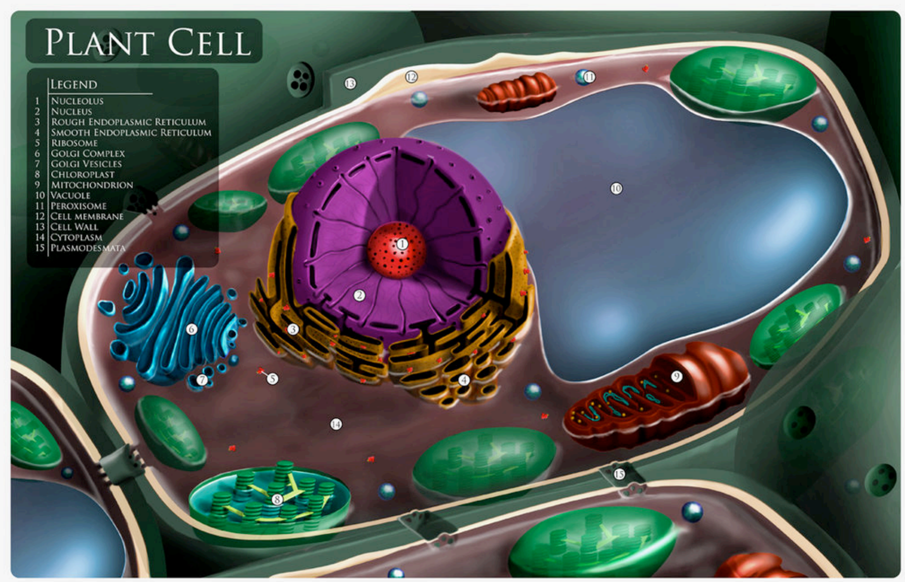

CALVIN CYCLE - SCHEMA
6 CO2
12 3-Phospho glycerate (PGA)
12 ATP
12 ADP
CARBOXYLATION
PHOSPHORYLATION
6 Ribulose bisphosphate (RuBP)
12 1,3 bisphosphoglyceric acid (DPGA)
PHOSPHORYLATION
REDUCTION
6 ADP
6 Ribulose 5 monophosphate
12 NADPH + H
REGENERATION
12 3-phosphoglyceraldehyde (PGAL)
10
2
6 ATP
1 GLUCOSE
12 Pi
12 NADP+
Projected changes in global temperature:
global average 1856-1999 and projection estimates to 2100
Global average temperature in °centigrade
IPCC estimate
High
Best (constant aerosol)
Best (increasing aerosol)
Low
1999
20°
19°
18°
17°
16°
15°
14°
1850 1870 1890 1910 1930 1950 1970 1990 2010 2030 2050 2070 2090
1900
2000
2100
GRID Arendal UNEP
Source : Temperatures 1856 - 1999: Climatic Research Unit, University at East Anglia, Norwich UK. Projections: IPCC report 95.

Contemporary biology is the study of *systems*.


Sun
Producers (rooted plants)
Producers (phytoplankton)
Primary consumers (zooplankton)
Secondary consumer (fish)
Dissolved chemicals
Tertiary consumer (turtle)
Sediment
Decomposers (bacteria and fungi)
© 2002 Brooks/Cole - Thomson Learning


Head & Arms
Jugular Vein
Carotid Artery
Superior Vena Cava
Aorta
Lungs
Lungs
Inferior Vena Cava
Liver
Digestive Tract
Kidneys
Trunk & Legs


PrEx 3.10/4:W52/6
MAP ROOM
WEST BERLIN
TRANSPORTATION SYSTEMS
GERMAN DEMOCRATIC REPUBLIC
FALKENSEE
Tegel Airport
EAST BERLIN
Gatow Airport
Tempelhof Airport
POTSDAM
TELTOW
Schönefeld Airport
DOCS PREX3.10/4:W52/6 PCL MAP VERT FILE COP.2
2111338716


PLANT CELL
LEGEND
1 NUCLEOLUS
2 NUCLEUS
3 ROUGH ENDOPLASMIC RETICULUM
4 SMOOTH ENDOPLASMIC RETICULUM
5 RIBOSOME
6 GOLGI COMPLEX
7 GOLGI VESICLES
8 CHLOROPLAST
9 MITOCHONDRION
10 VACUOLE
11 PEROXISOME
12 CELL MEMBRANE
13 CELL WALL
14 CYTOPLASM
15 PLASMODESMATA

Systems Thinking Skills:

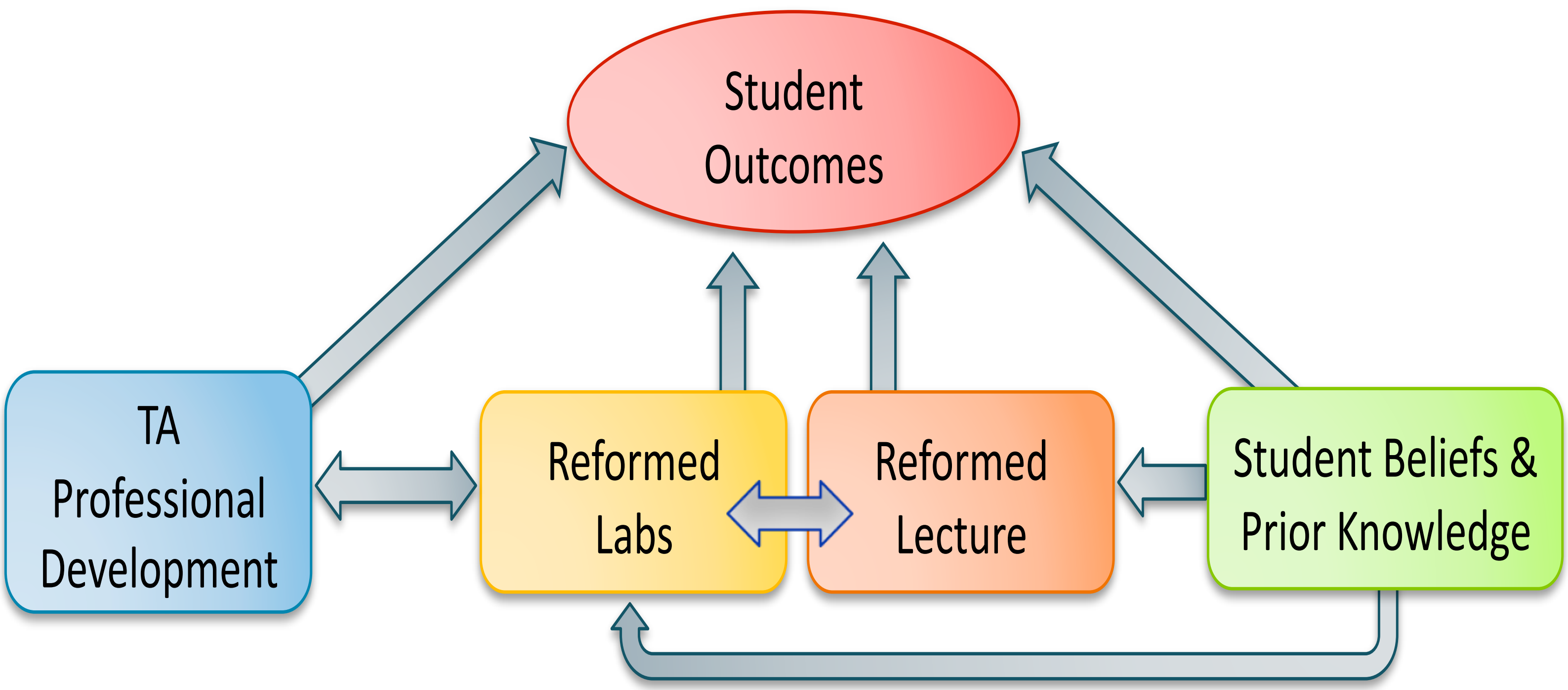
- Identify system components and processes
- Organize into a meaningful framework, based on system interactions
- Understand dynamic nature of interactions that traverse scales (space, time)
- Identify and predict system feedbacks, cycles, and emergent properties

(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.



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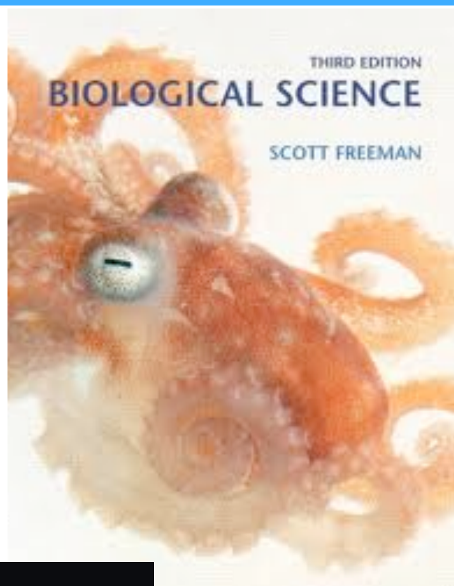
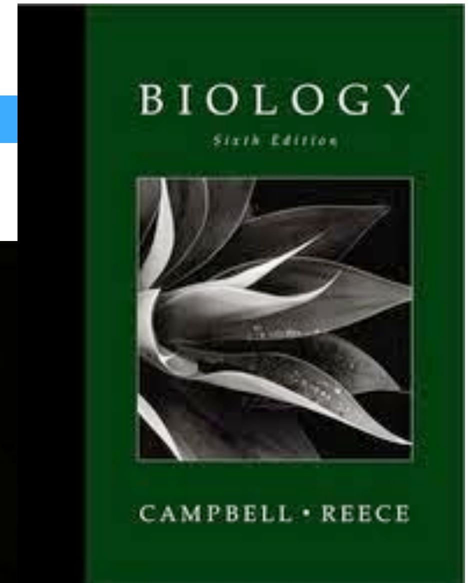
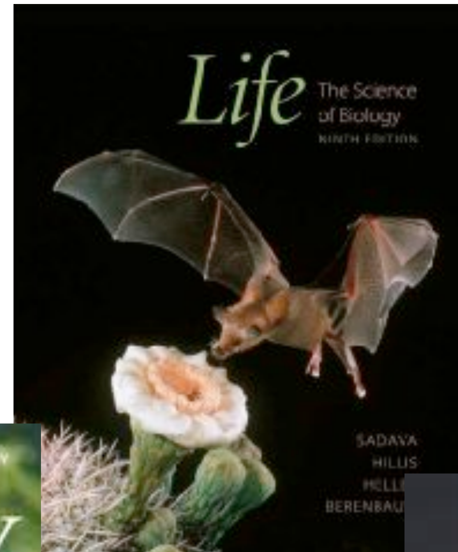
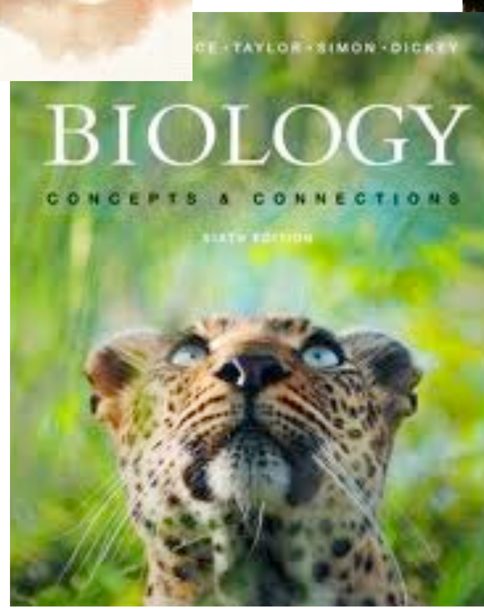
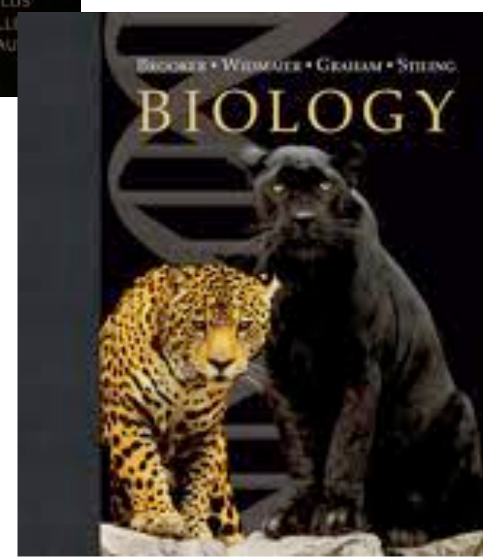
How do we (most university faculty) design a course?











Backward Design

What should students know, be able to do?

What evidence will we accept?

How can we best prepare students?

Adapted from Wiggins and McTighe (1998)

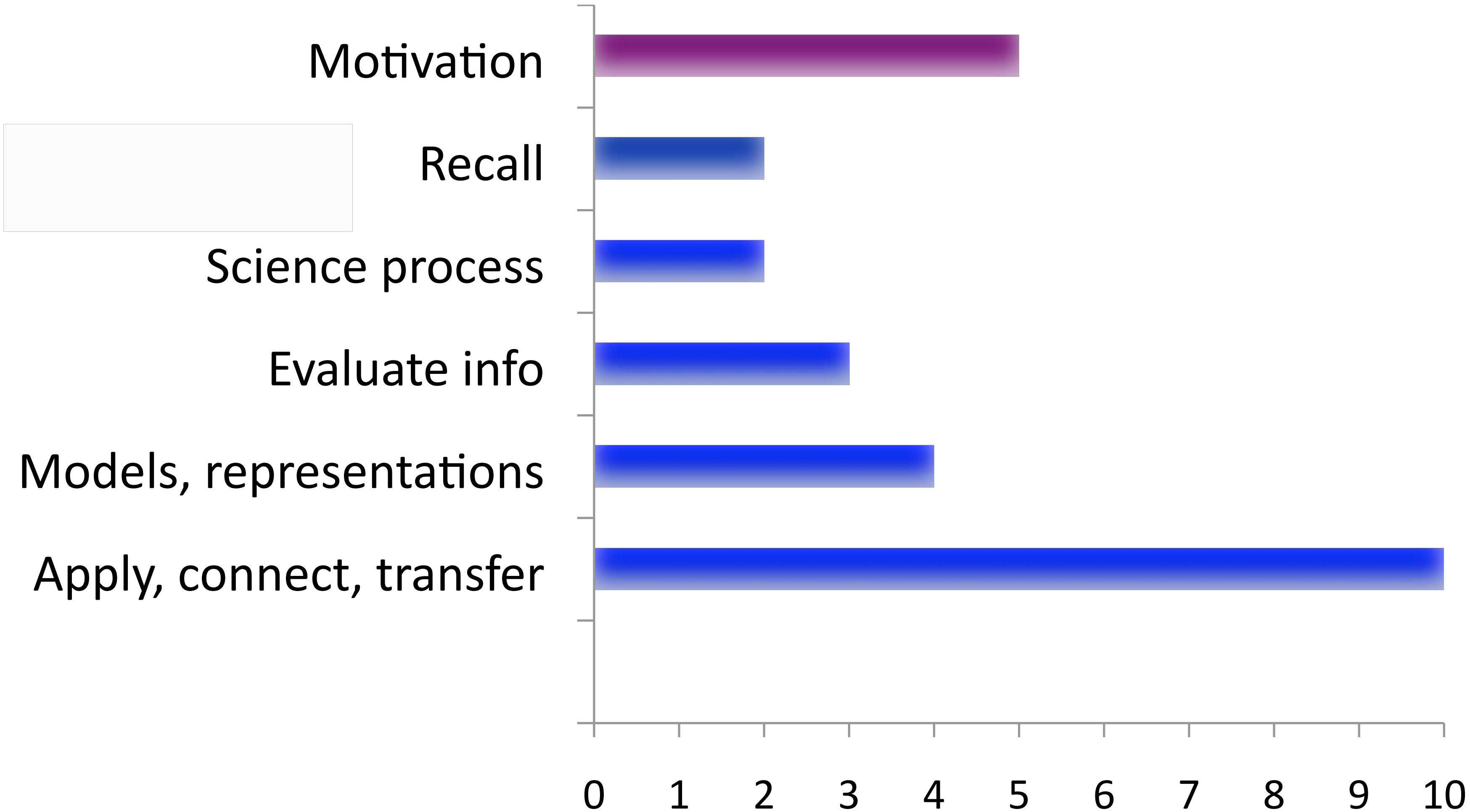
Goals for Intro Bio

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)



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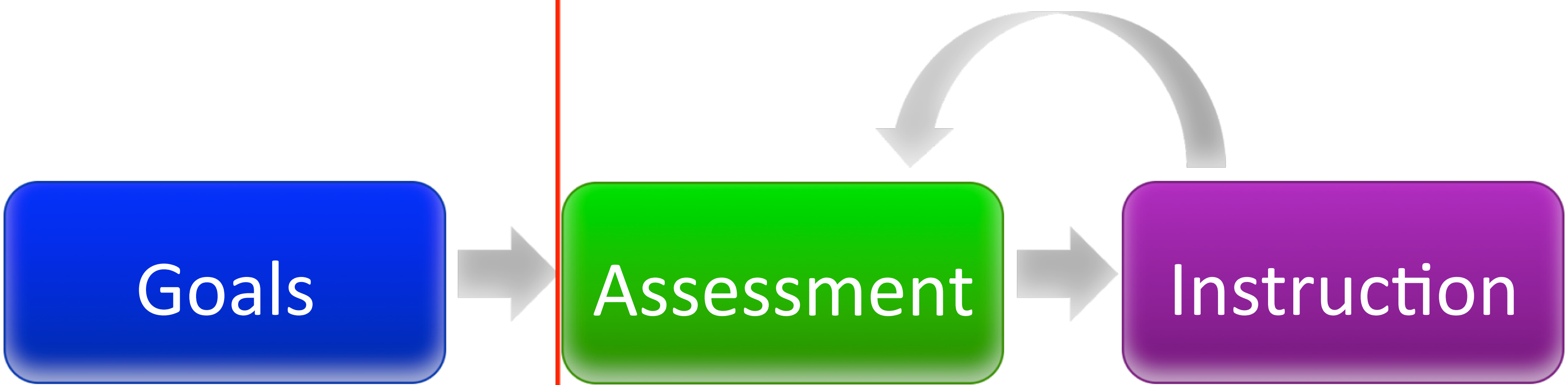
Program	• Prepare students for upper-division coursework - Foundational knowledge in genetics, ecology, evolution
Faculty	• Apply concepts • Make connections • Transfer principles

Backward Design



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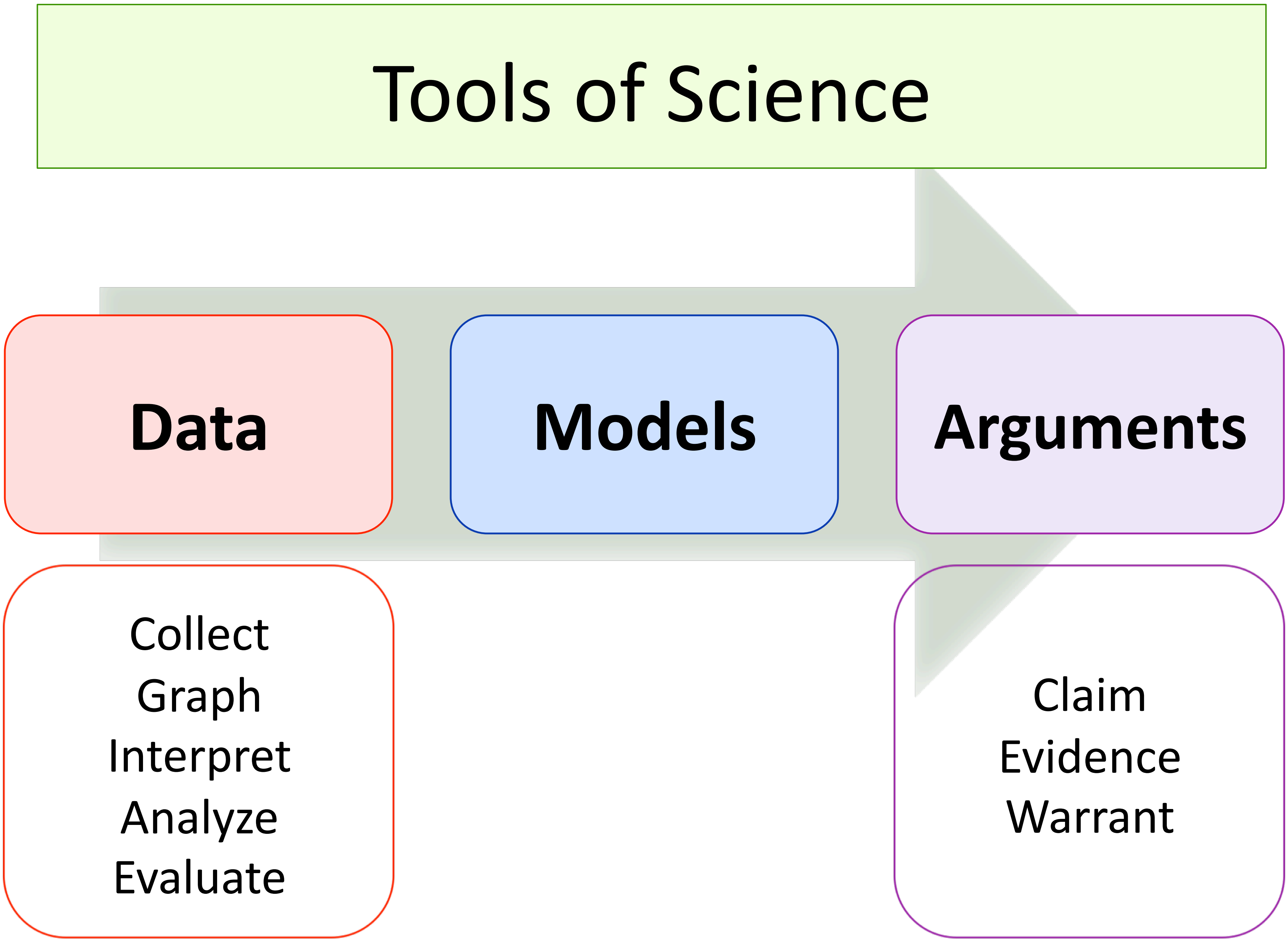
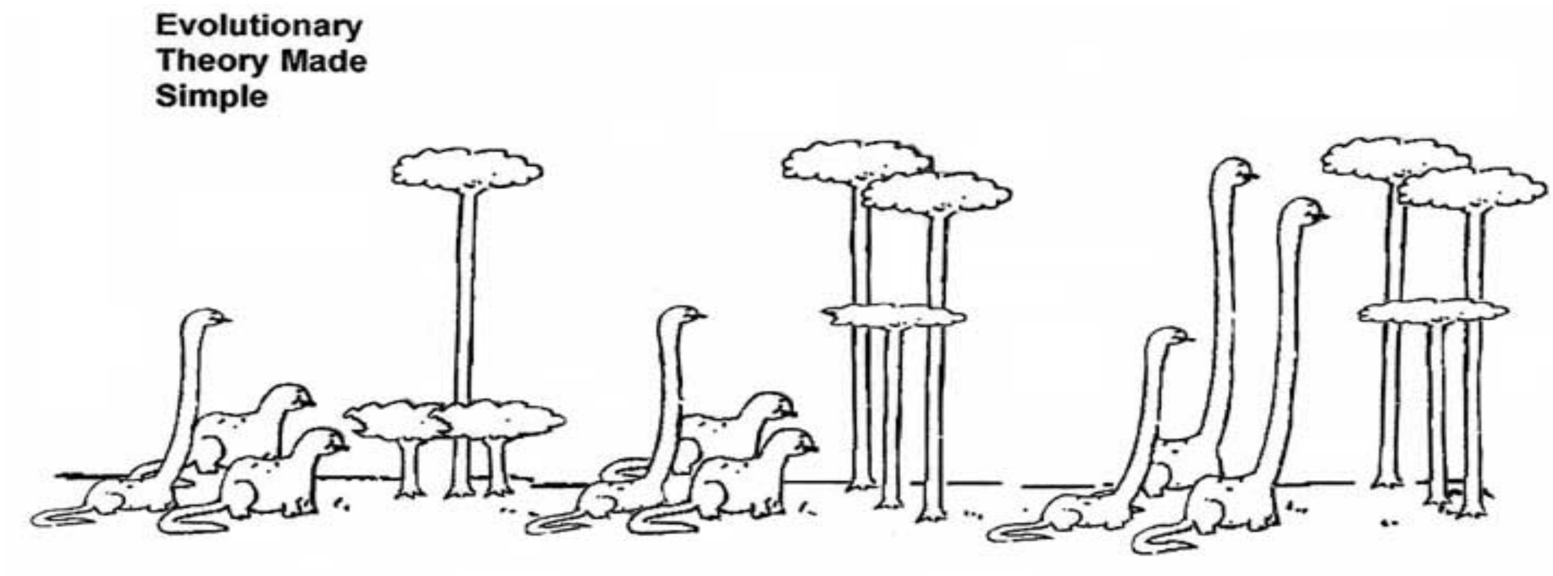
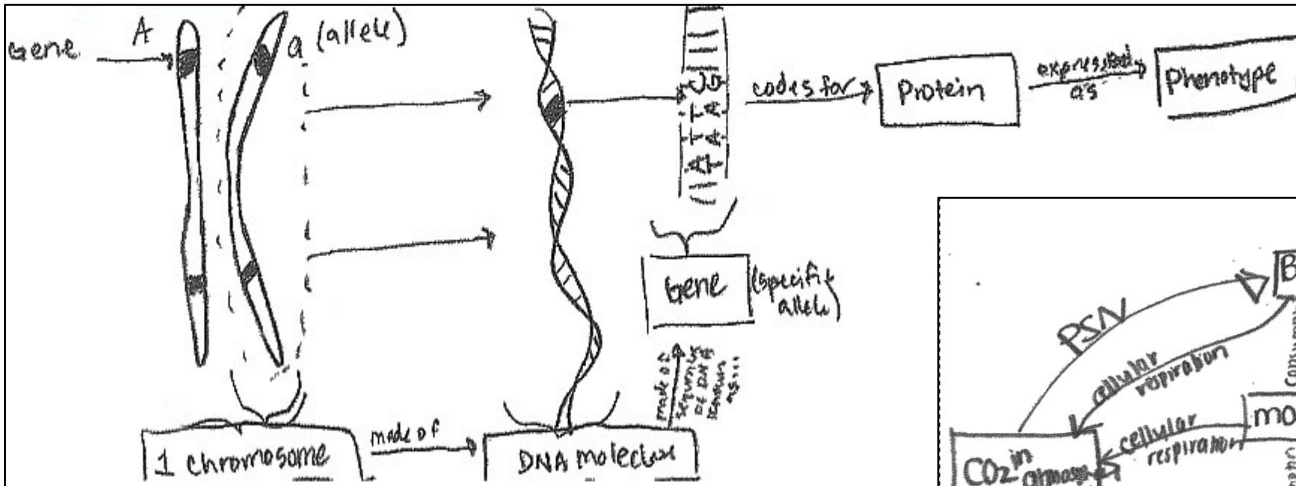
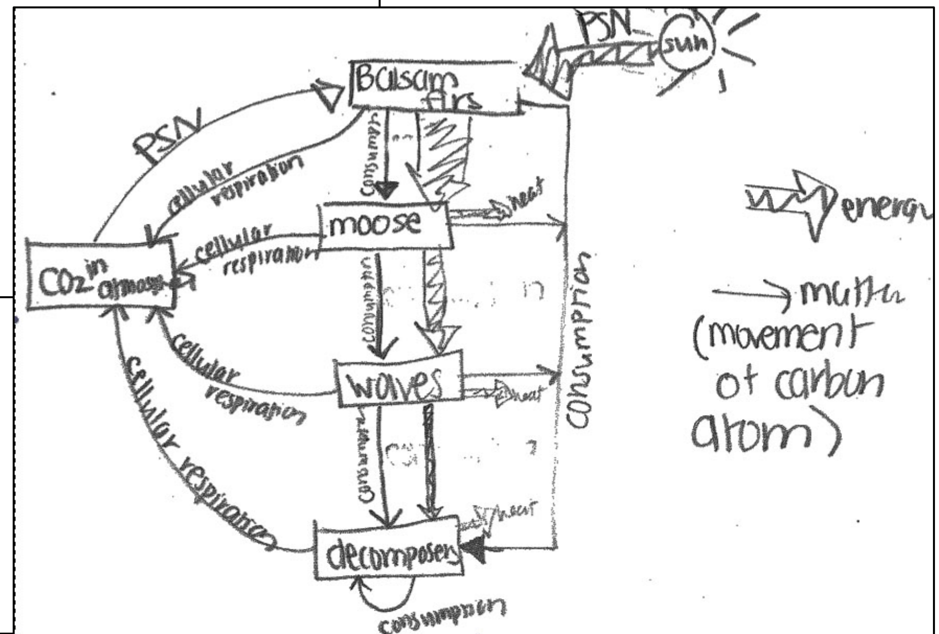

Tools of Science
Data
Models
Arguments
Collect
Graph
Interpret
Analyze
Evaluate
Claim
Evidence
Warrant



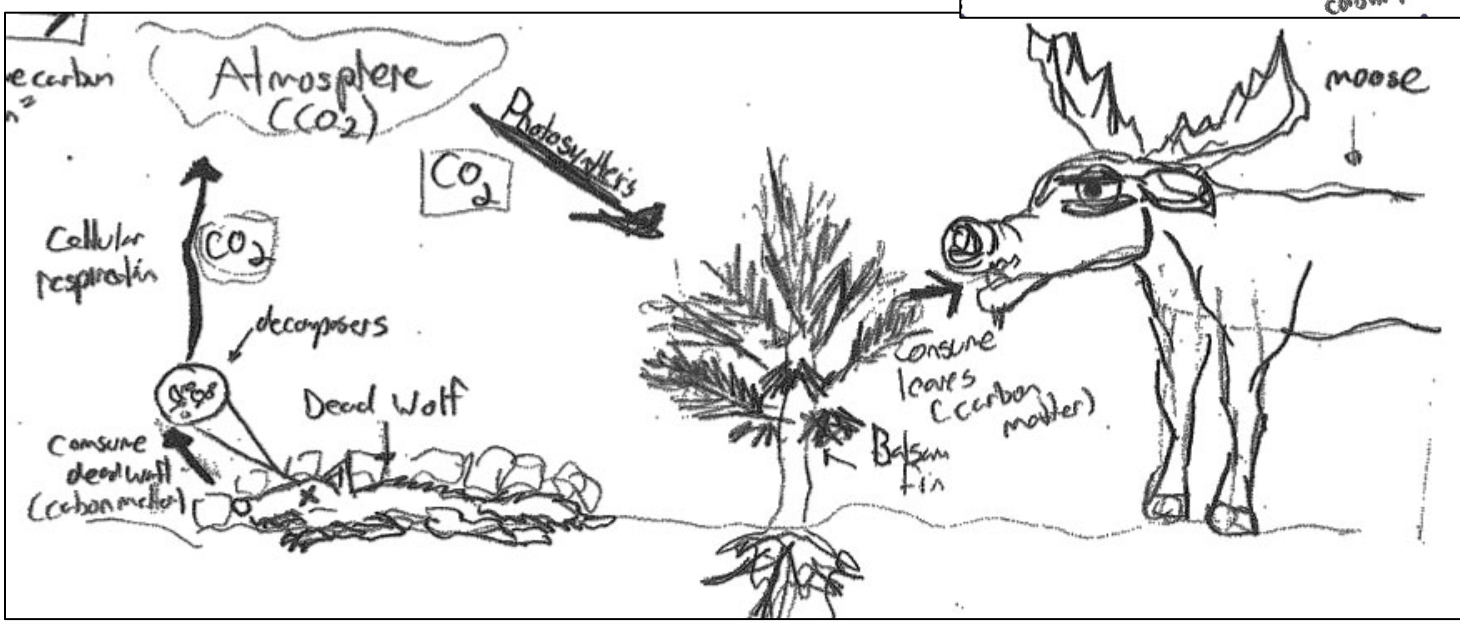
- The trees in section one that are smaller grow taller so that they can compete with the larger tree for sunlight. When this happened, the short-necked animals weren't able to eat as well as the dino with a long neck. The idea is that in box two, the long-necked dino survives because it is able to obtain 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, offfspring with longer necks are more fit to eat and survive to produce offspring. Thus, in box 3, the long-necked dinos are present.



Gene
A
a (allele)
codes for
Protein
expressed as
Phenotype
Gene (specific allele)
1 chromosome
made of
DNA molecule



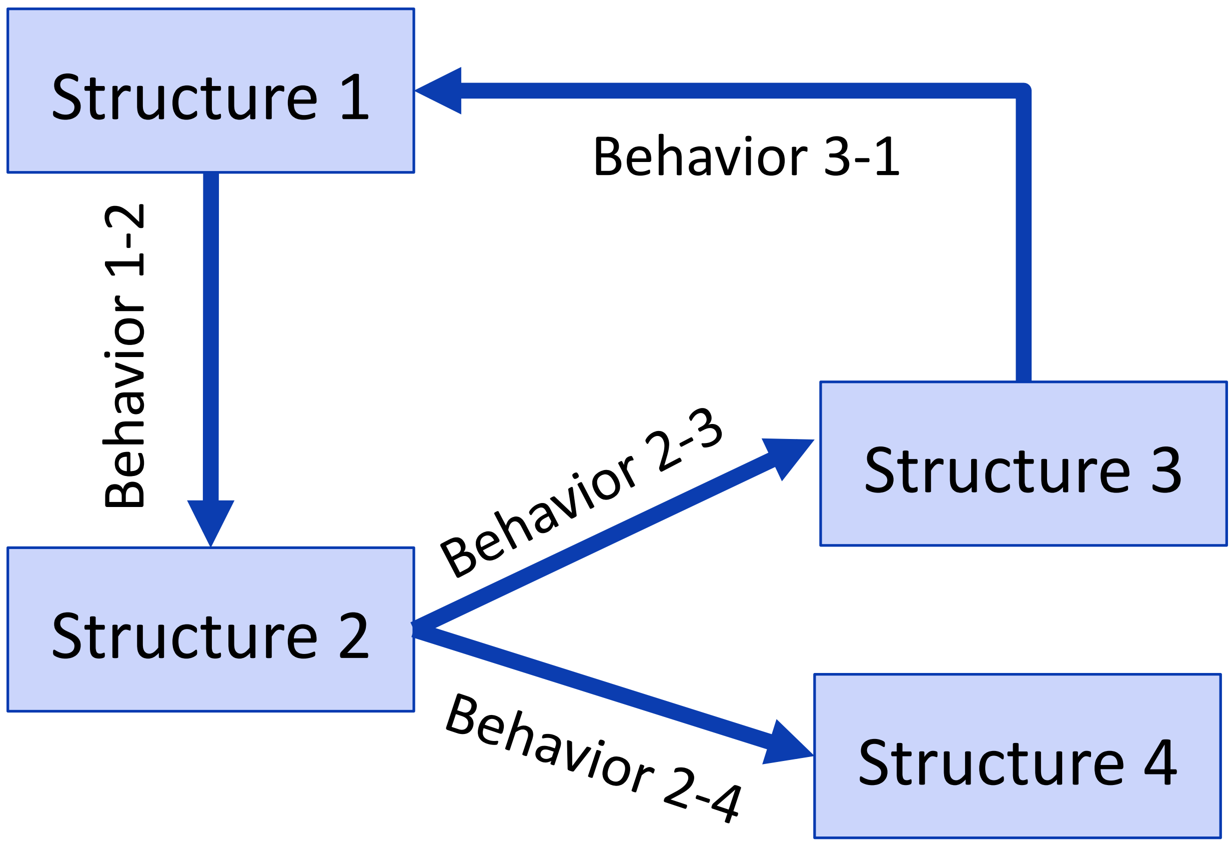
PSN
sun
Balsam firs
PSN
cellular respiration
consumption
moose
heat
CO2 in atmosphere
cellular respiration
consumption
cellular respiration
wolves
heat
cellular respiration
consumption
consumption
decomposers
heat
consumption
energy
matter
(movement of carbon atom)



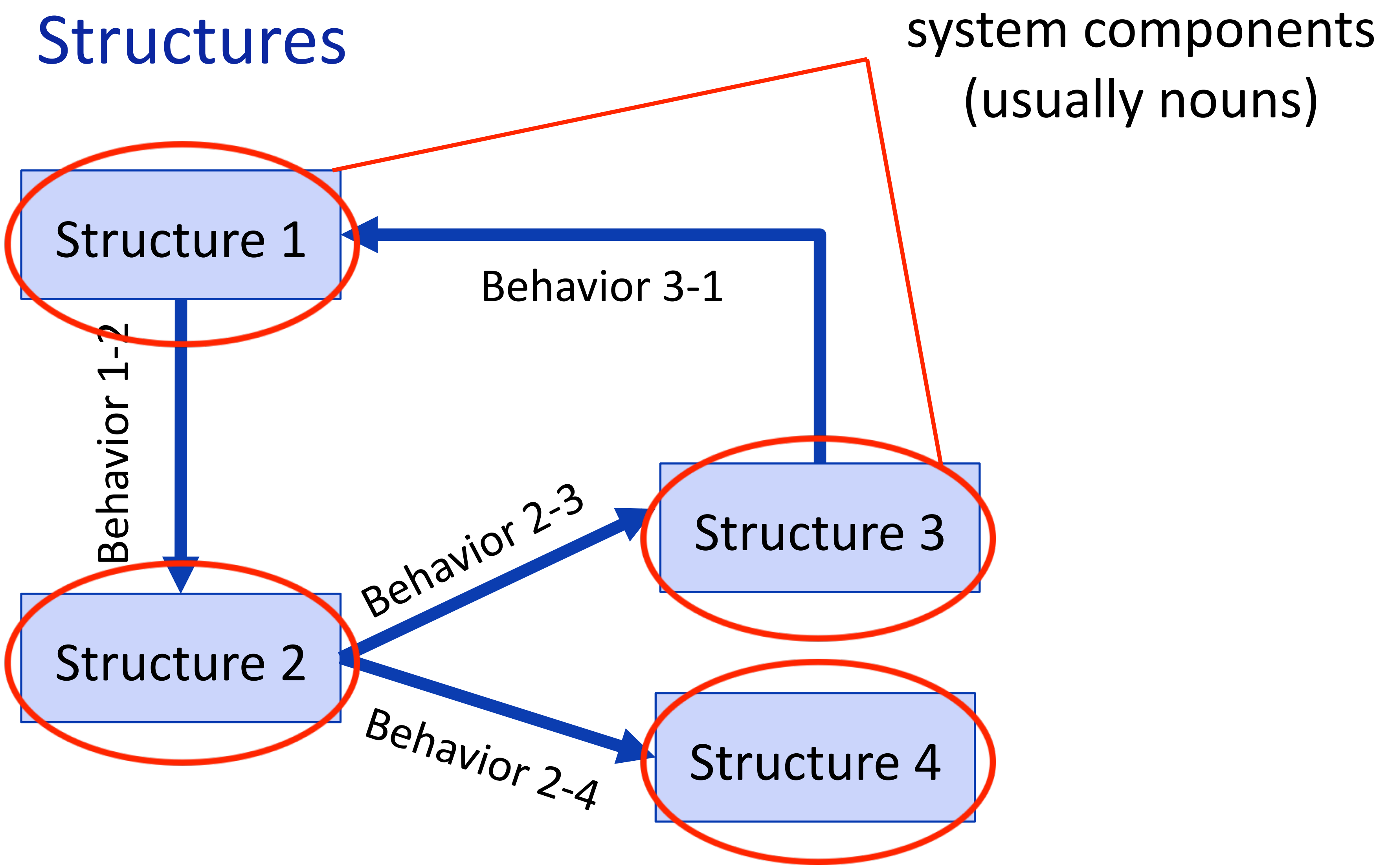
Atmosphere (CO2)
CO2
Photosynthesis
moose
Cellular respiration
CO2
decomposers
Dead Wolf
Consume dead wolf (carbon matter)
Consume leaves (carbon matter)
Balsam fir

System Model

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



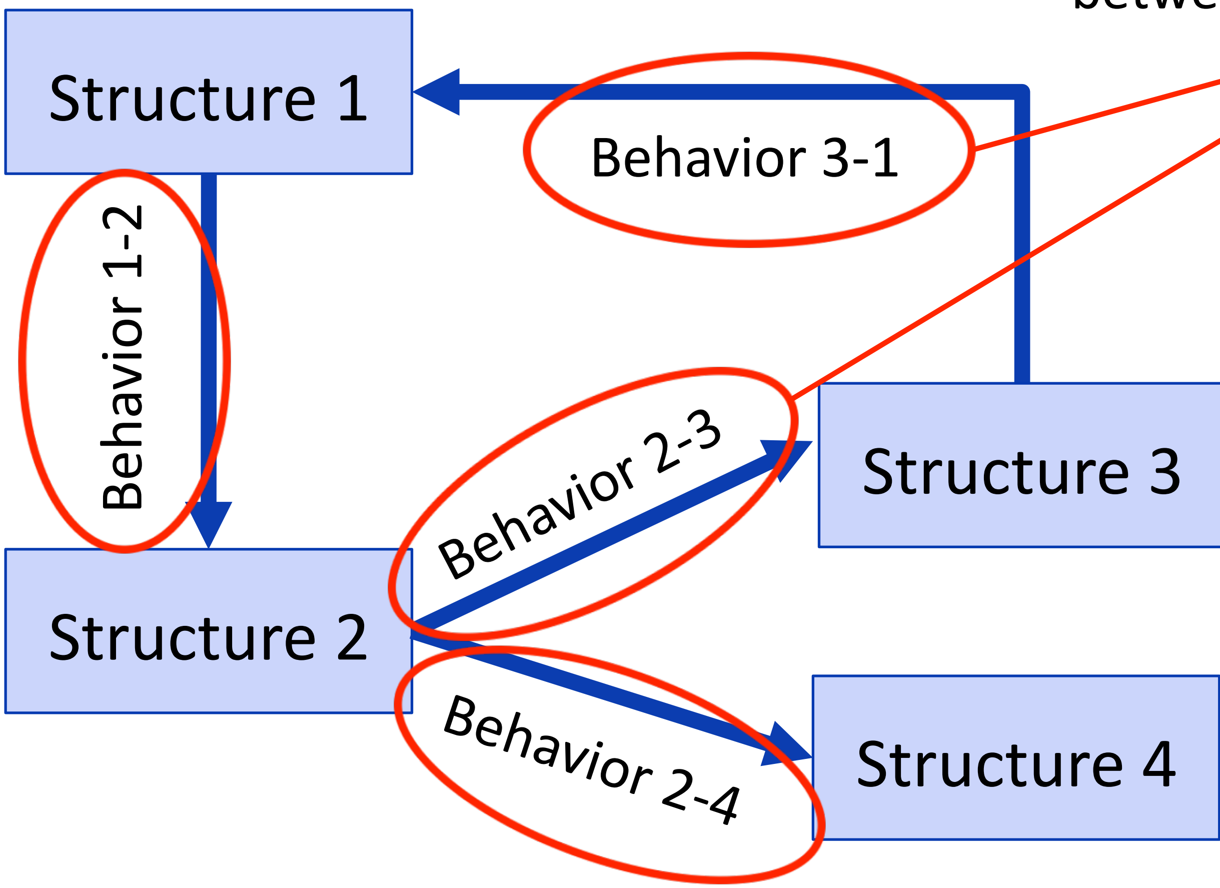
Structures


system components
(usually nouns)
Structure 1
Behavior 3-1
Behavior 1-2
Structure 3
Behavior 2-3
Structure 2
Structure 4
Behavior 2-4

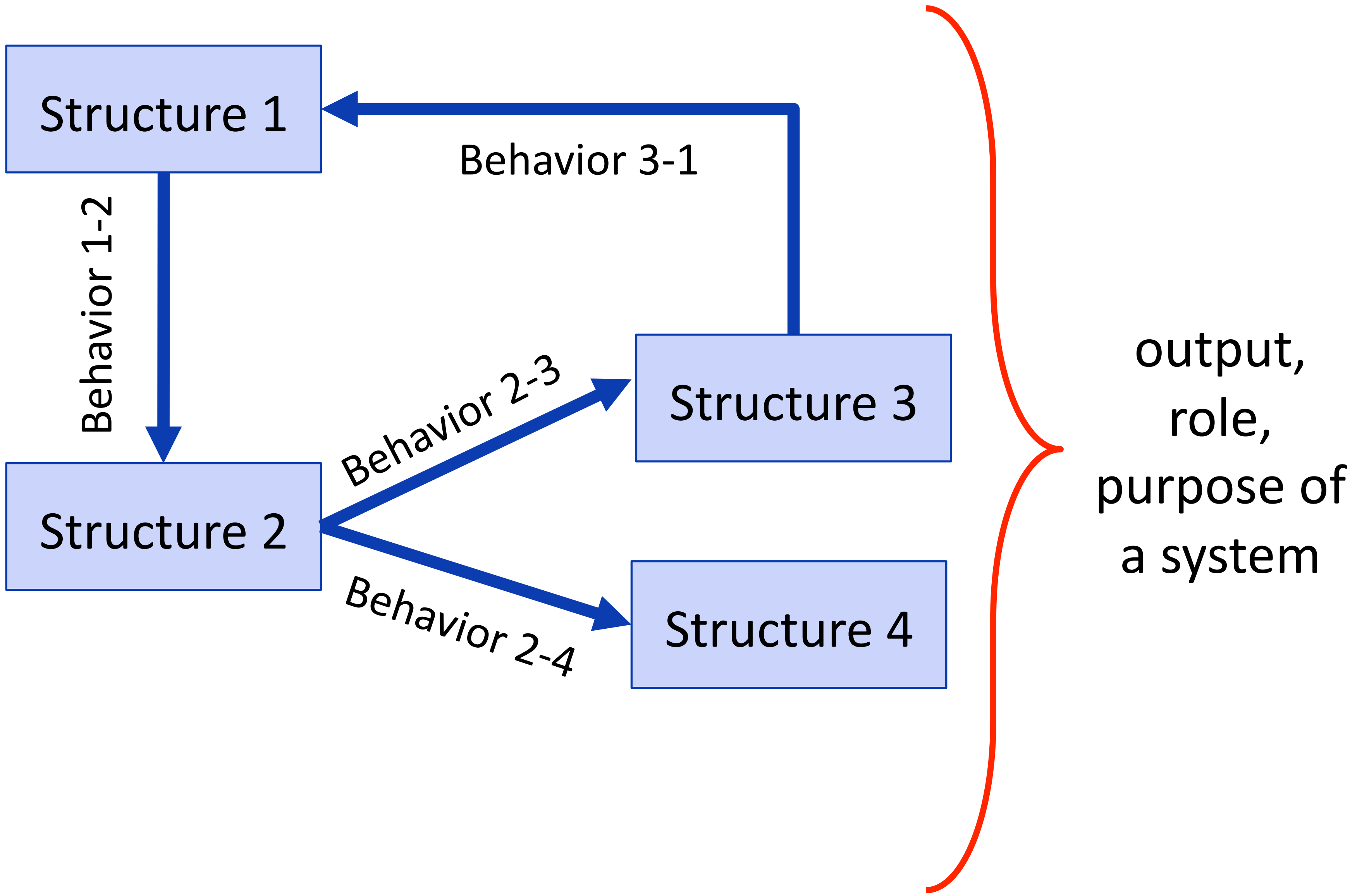
Behaviors

system processes
(usually verbs)

- describe relationships between pairs of structures.



Function


Structure 1
Behavior 3-1
Behavior 1-2
Behavior 2-3
Structure 3
Structure 2
Behavior 2-4
Structure 4
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?

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Simplifying Complexity:

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- Do students use models to formulate predictions and explanations?
- How do students evaluate models?
- Are student-constructed models accurate representations of their thinking?

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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):

Nucleotide	CTG	ACT	CCT	GAG	GAG	AAG	TCT
Amino Acid	Leu	Thr	Pro	Glu	Glu	Lys	Ser
	3			6			9

HBB Sequence in Mutant Adult Hemoglobin (Hb S):

Nucleotide	CTG	ACT	CCT	GTG	GAG	AAG	TCT
Amino Acid	Leu	Thr	Pro	Val	Glu	Lys	Ser
	3			6			9

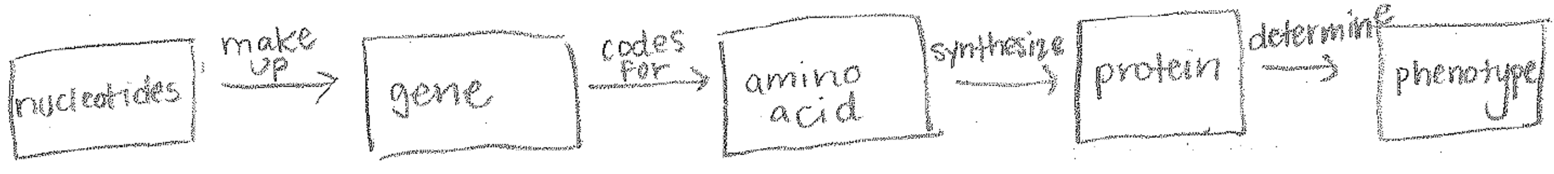
Late in semester:

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

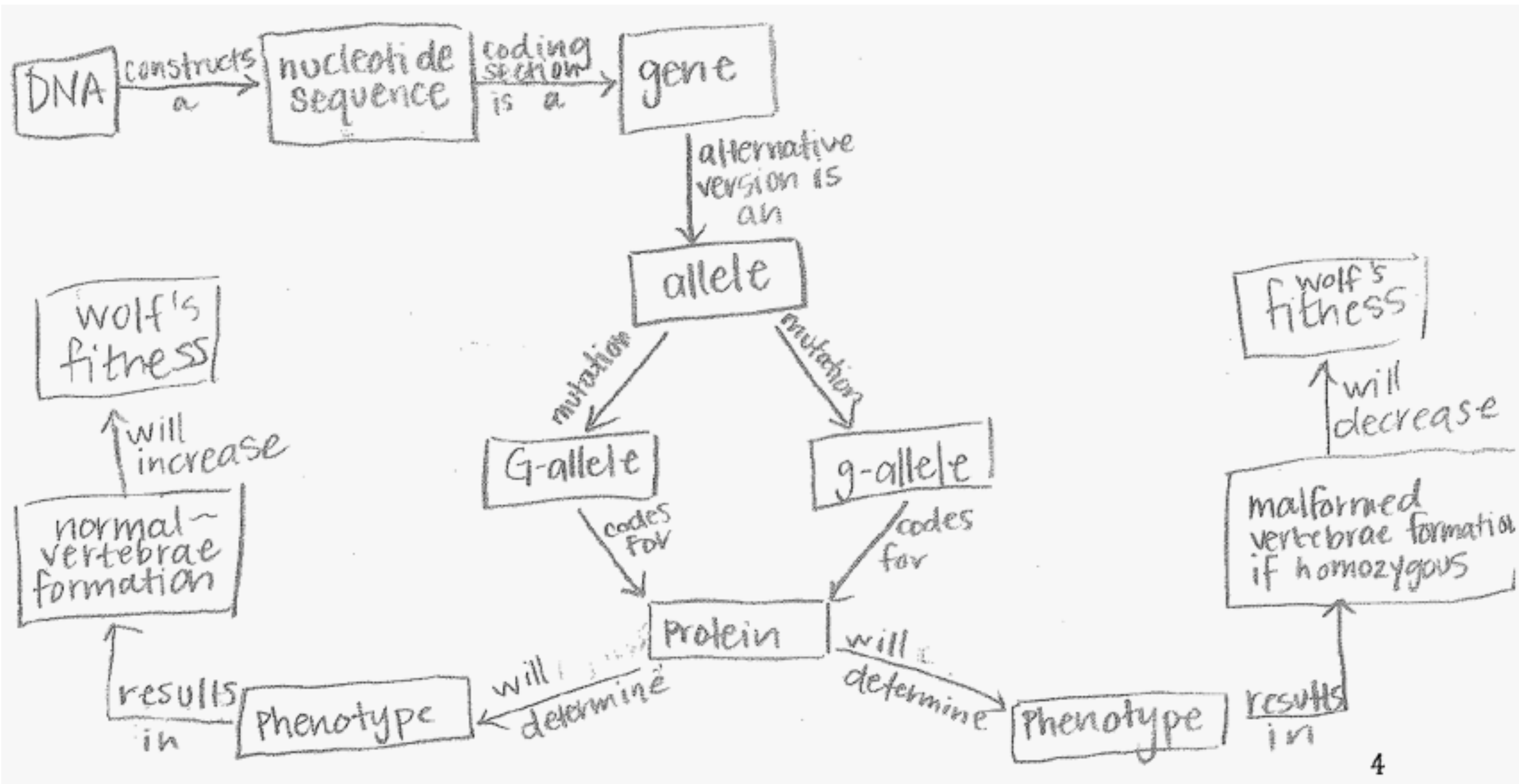
a) explain how genetic variation originates and is expressed;
b) illustrate the consequences of phenotypic variation on fitness within the population; and,
c) be context-specific for the case provided.

- Gene
- Chromosome
- Protein
- Nucleotide
- Phenotype
- DNA
- Allele
- Fitness

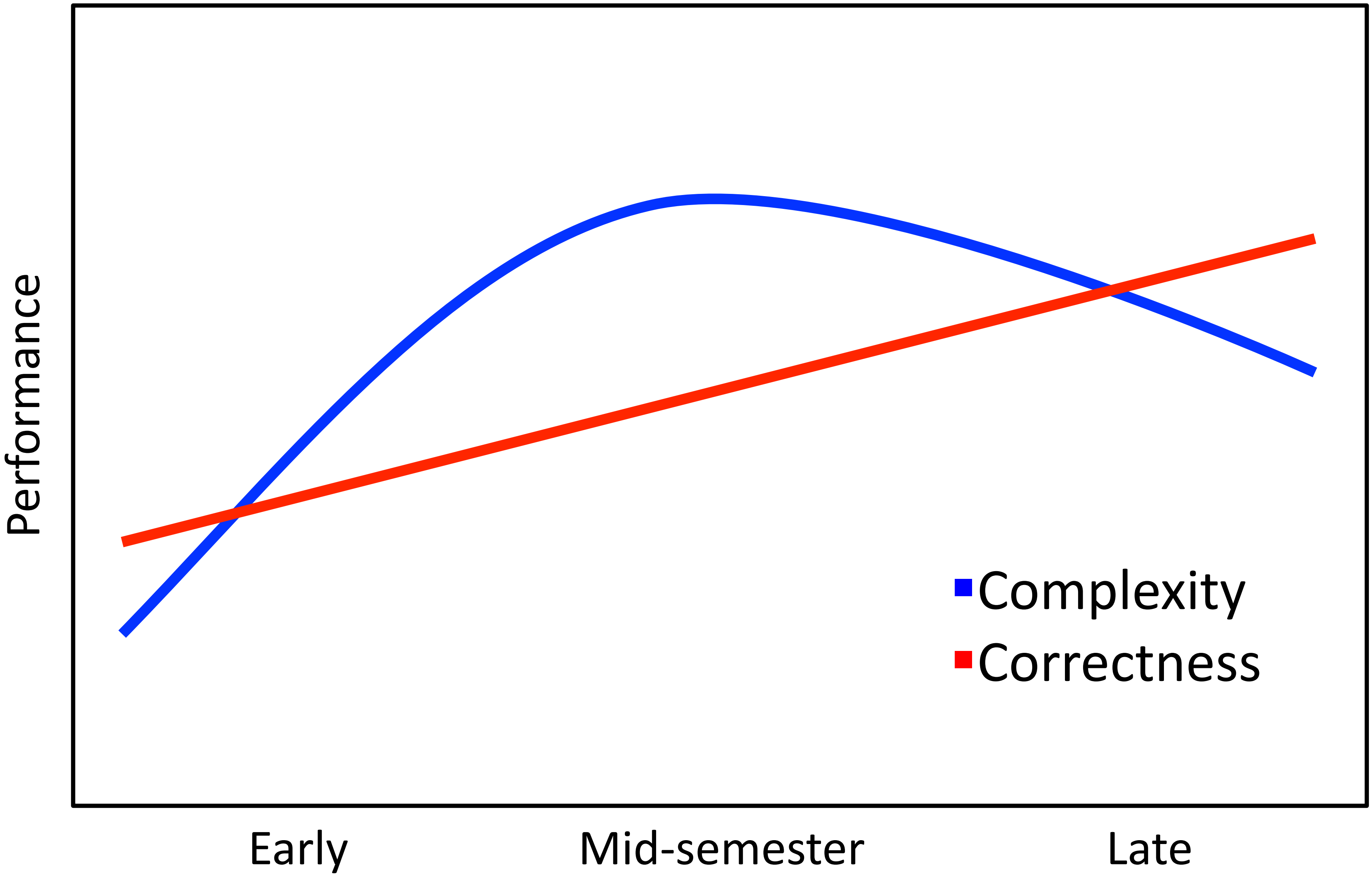
Quiz 2:


nucleotides
make up
gene
codes for
amino acid
synthesize
protein
determine
phenotype

Final:


DNA
constructs a
nucleotide sequence
coding section is a
gene
alternative version is an
allele
mutation
mutation
G-allele
g-allele
codes for
codes for
Protein
will determine
will determine
Phenotype
Phenotype
results in
results in
normal vertebrae formation
malformed vertebrae formation if homozygous
will increase
will decrease
wolf's fitness
wolf's fitness
4

Change in Model Metrics Over Time



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

Acknowledgements

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- Sasha Makohon-Moore
- Andy George
- Megan Gustafson
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