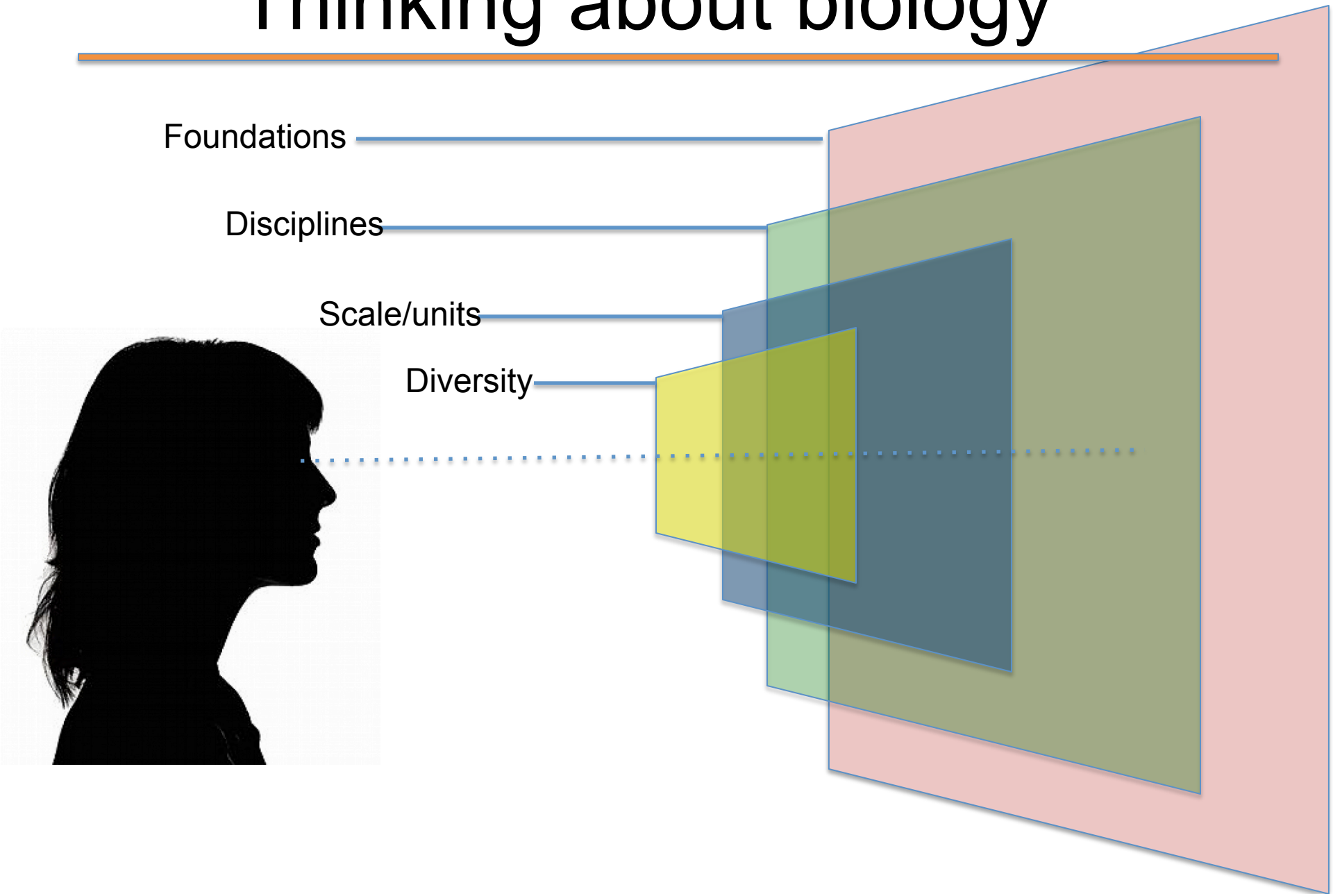
Thinking About Evolutionary Change: Concepts, Contexts, and Cognitive Coherence

Ross Nehm
Associate Professor, Dept. of Ecology & Evolution
Associate Director, Ph.D. Program in Science Education

Stony Brook University
SUNY

Thinking about biology



Thinking about biology

Foundations

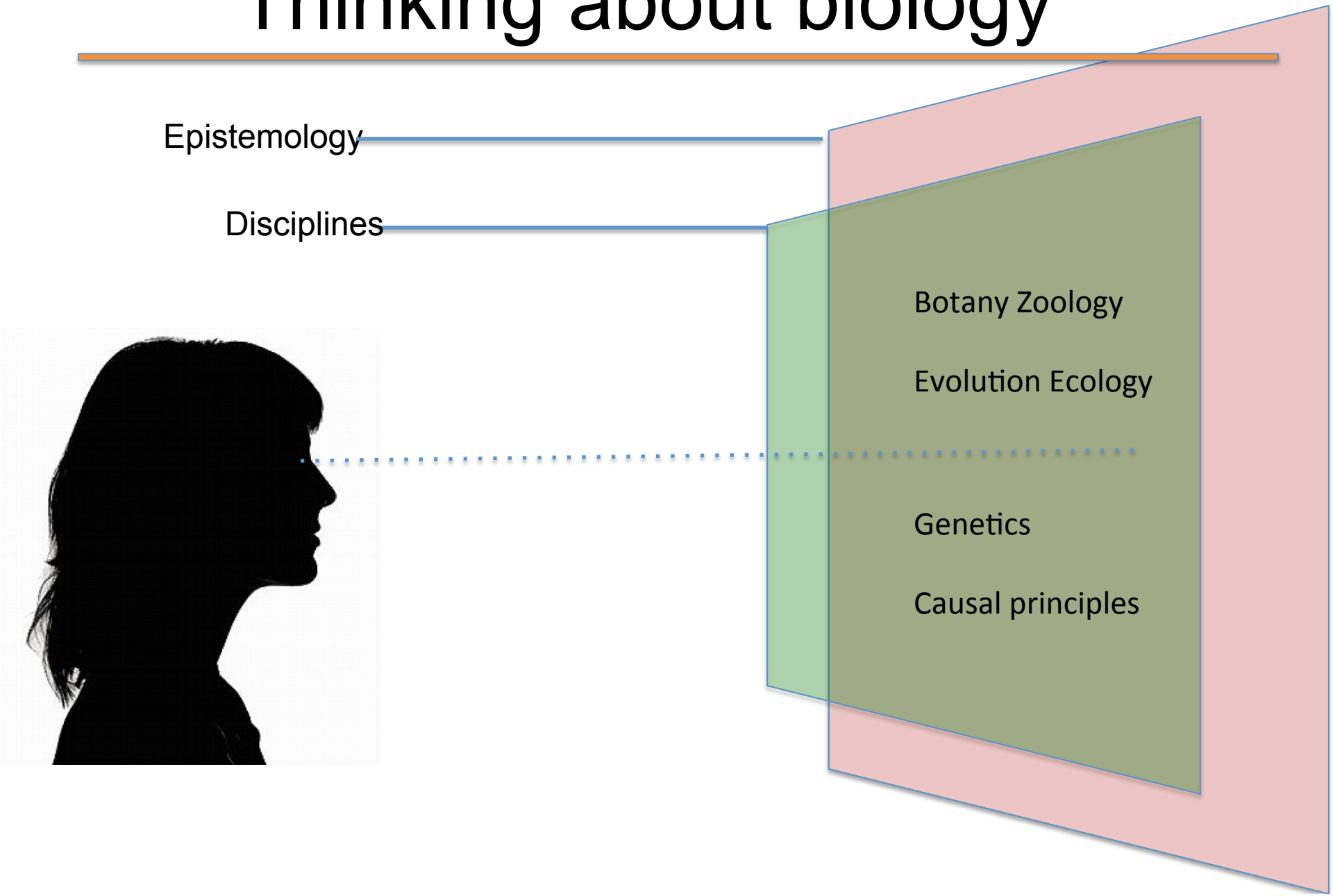
Heterogeneity of units

Probabilistic vs. deterministic outcomes

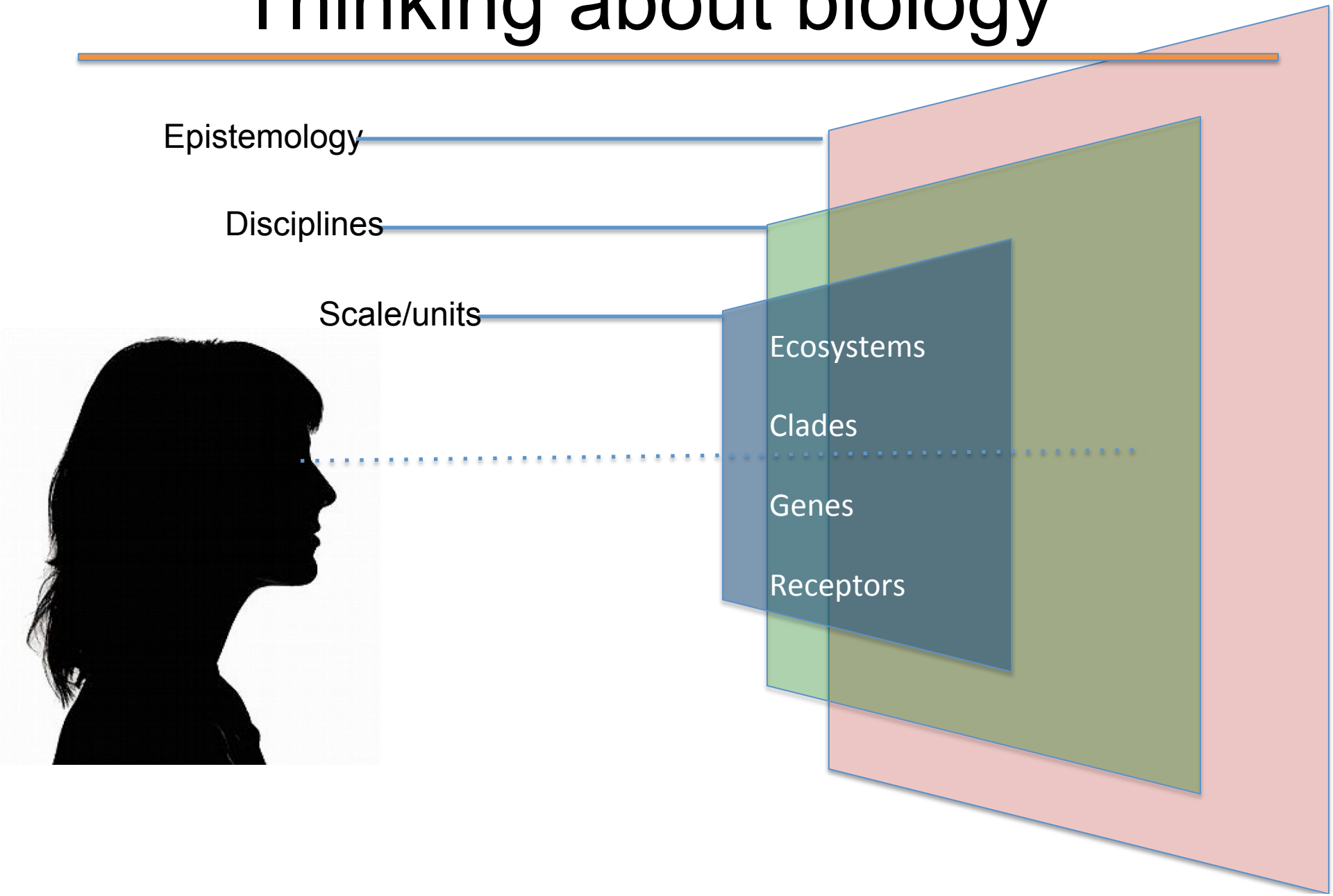
Many causes, weak effects (vs. few causes with strong effects)

Historical contingency of systems

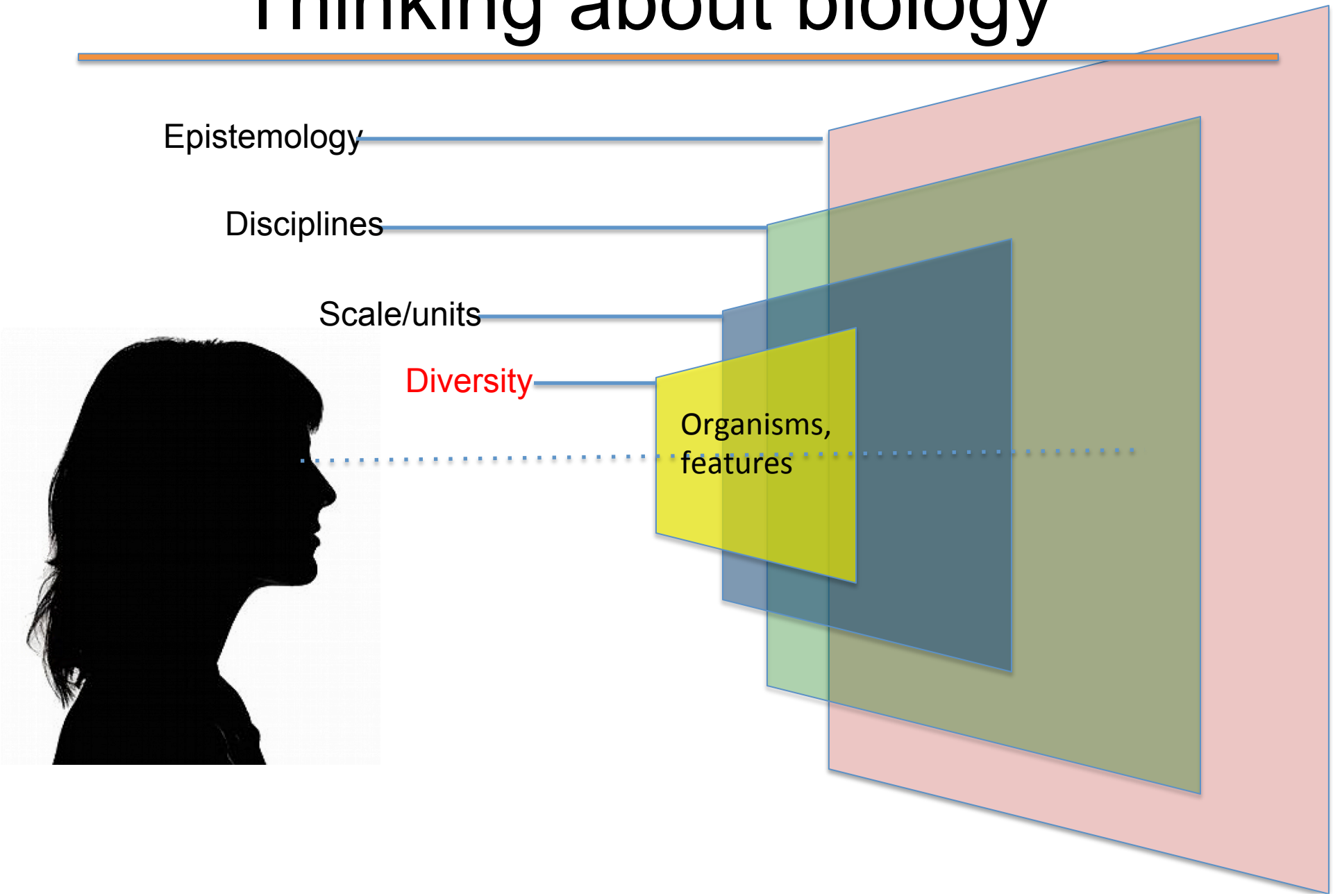
Thinking about biology



Thinking about biology



Thinking about biology



Unity & diversity of life

Source: Wikipedia

Dobzhansky

- Unity—what is the same and why?
- Diversity—what is different and why?

Unity & diversity of life

Source: Wikipedia

Dobzhansky

- Unity—what is the same and why?
- Diversity—what is different and why?
- How do humans at different educational levels think about biological similarities and differences across scales and contexts?
- What types of causal processes are invoked to explain similarities and differences across biological scales and contexts?

Diversity & unity across scales

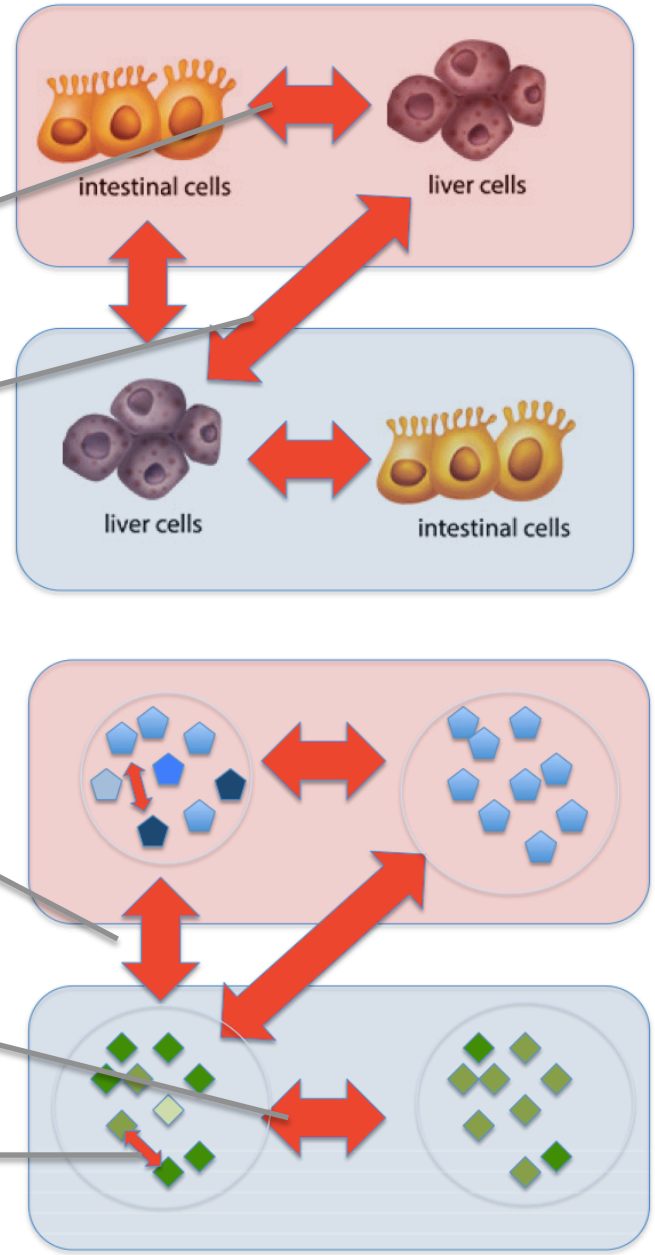
Different cell types
same taxa

Same cell type
different taxa

Differences
between
populations of
different taxa

Between
populations of the
same taxon

Between
individuals in a
population



Thinking about biology

Diversity

Spectacular phenotypic differences among lineages—and special similarities. The phenomena experienced most directly during human ontogeny.




Unity

Causal similarity: genetic, developmental, and evolutionary processes occur across the tree of life. Unobservable processes least directly experienced during ontogeny.

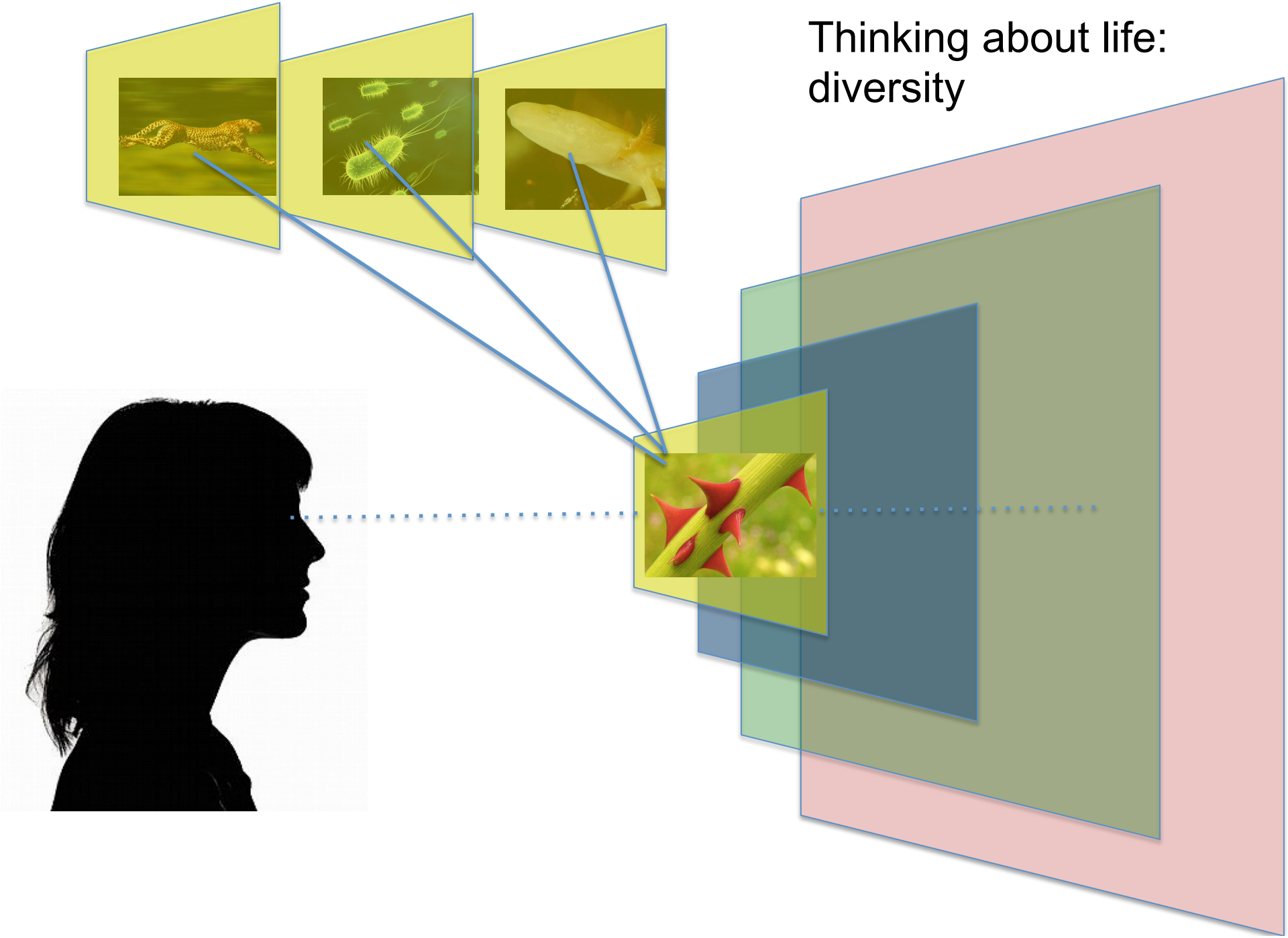
Biology Education Research

- We have thousands of studies of student learning difficulties in biology (e.g., see Duit bibliography).

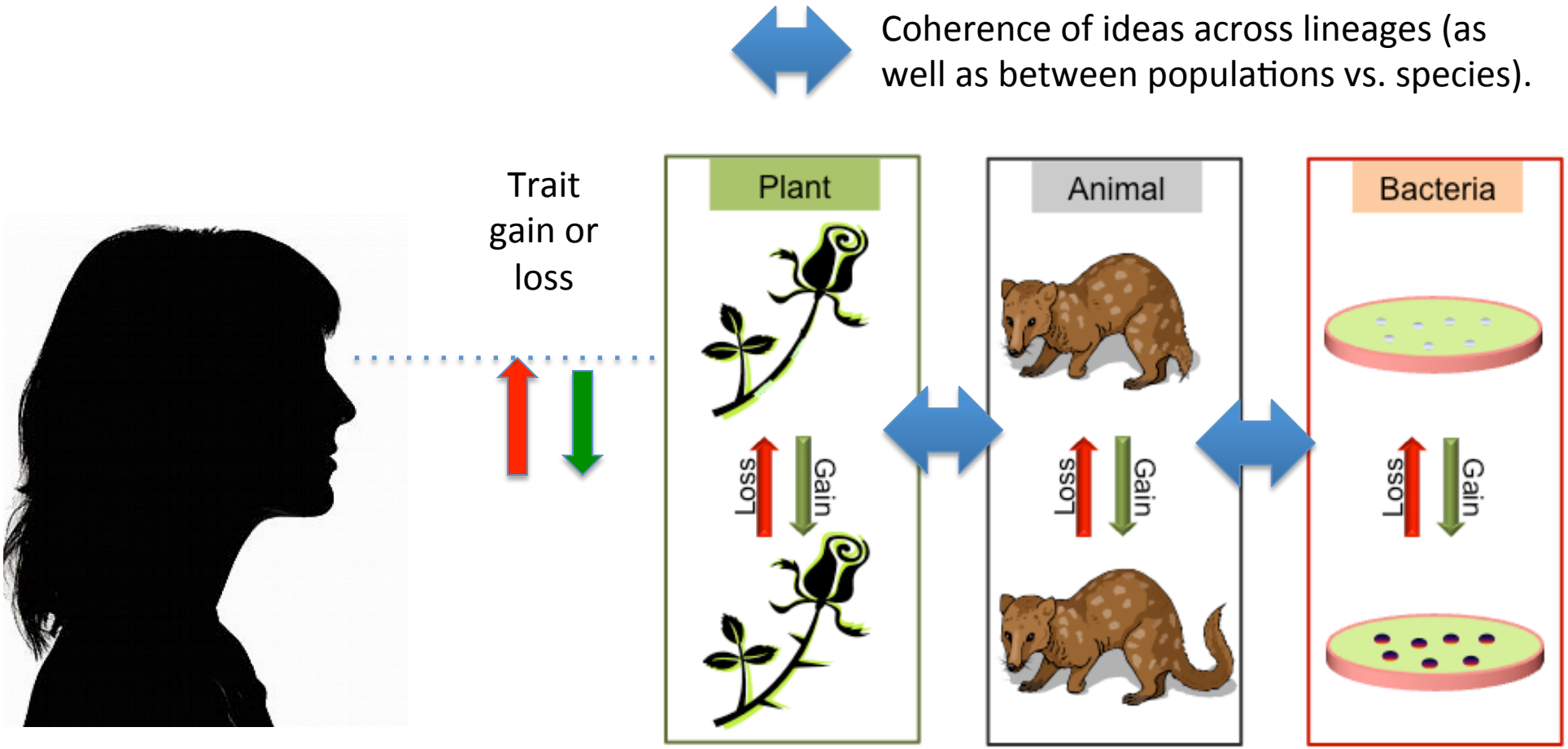
- What robust, generalizable claims can be made about student thinking about life?

- An important goal of all disciples should be work towards causal principles that have broad explanatory power.

Thinking about life: diversity



Contexts and evolutionary reasoning: experiments



ACORNS instrument (Nehm et al. 2012)

Experimental research design to try to establish generalizable findings about student reasoning.

```
[1.How would biologists] explain how a [2.
species] of [3. cactus] [4. with] [5. spines]
evolved from a [species] of [cactus] [without]
[spines]?
```

(1) Middle school reading level, but can be used with expert biologists.

(2) Framed from the perspective of a biologist, so it avoids recruitment of personal beliefs (cues scientific explanation).

(3) Level of biological organization, or scale (population vs. species).

(4) Taxon or clade (plant, animal, fungus, bacteria).

(5) Polarity of change (gain or loss of a trait or feature).

(6) Trait (functional, non-functional; morphological, genetic).

Written (or oral) explanations

How would biologists explain how a species of cactus with spines evolved from a species of cactus without spines?

The cacti without spines had to have developed spines over time [A] due to changes in its environment such as *to prevent itself* [N] *from harm from other threats* [R]. *This trait of having spines therefore became favorable* [D] and *the trait will be passed down by generation to the next offspring and so on* [H]. Therefore, the cacti today all have spines.

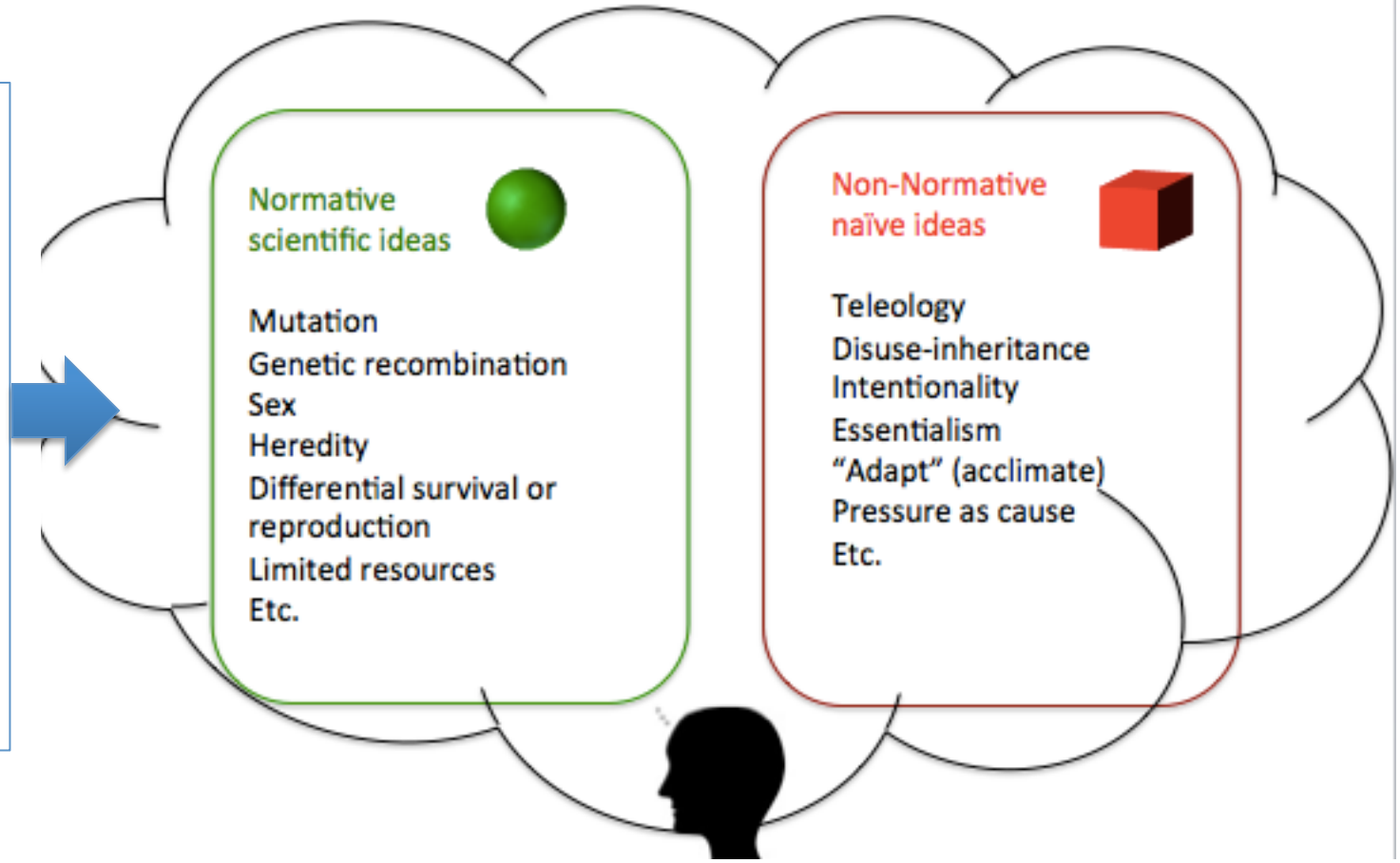
Concepts (composition)

Model (how concepts are arranged or structured)

12,000 + written explanations, 100+ interviews

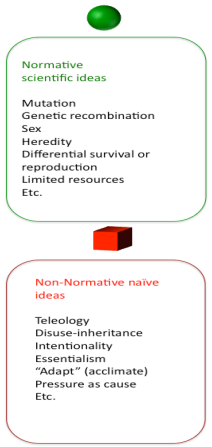
Categorizing **concepts** students use to explain evolutionary change

The cacti without spines had to have developed spines over time [A] due to changes in its environment such *as to prevent itself* [N] *from harm from other threats* [R]. *This trait of having spines therefore became favorable* [D] and *the trait will be passed down by generation to the next offspring and so on* [H]. Therefore, the cacti today all have spines.

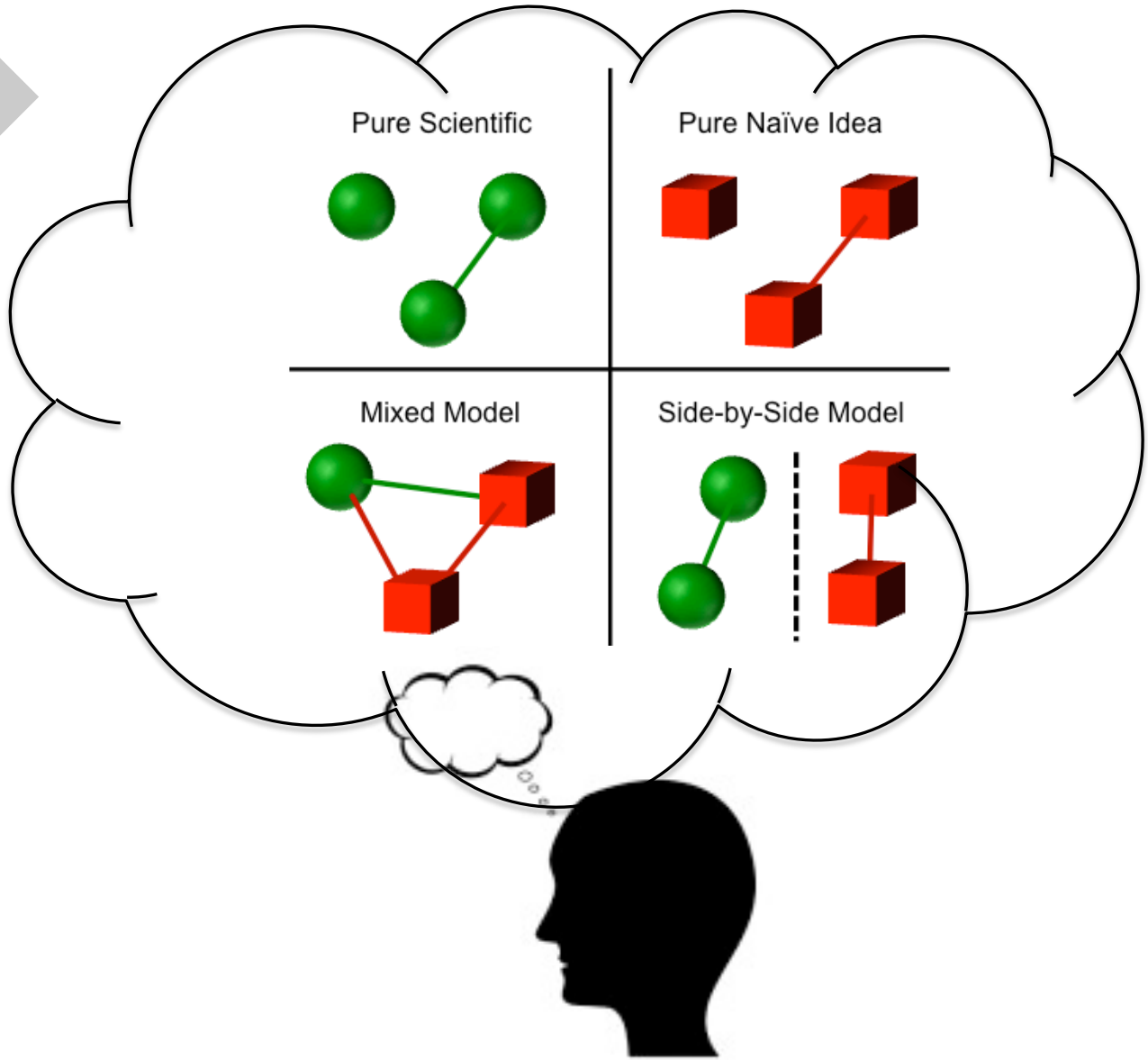


From concepts to **models**

Nehm et al. (2012)

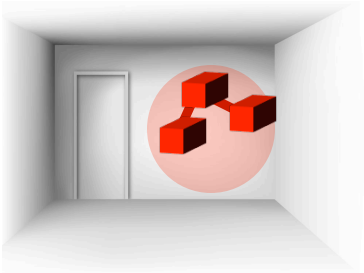


The cacti without spines had to have developed spines over time [A] due to changes in its environment such as *to prevent itself* [N] *from harm from other threats* [R]. *This trait of having spines therefore became favorable* [D] and *the trait will be passed down by generation to the next offspring and so on* [H]. Therefore, the cacti today all have spines.

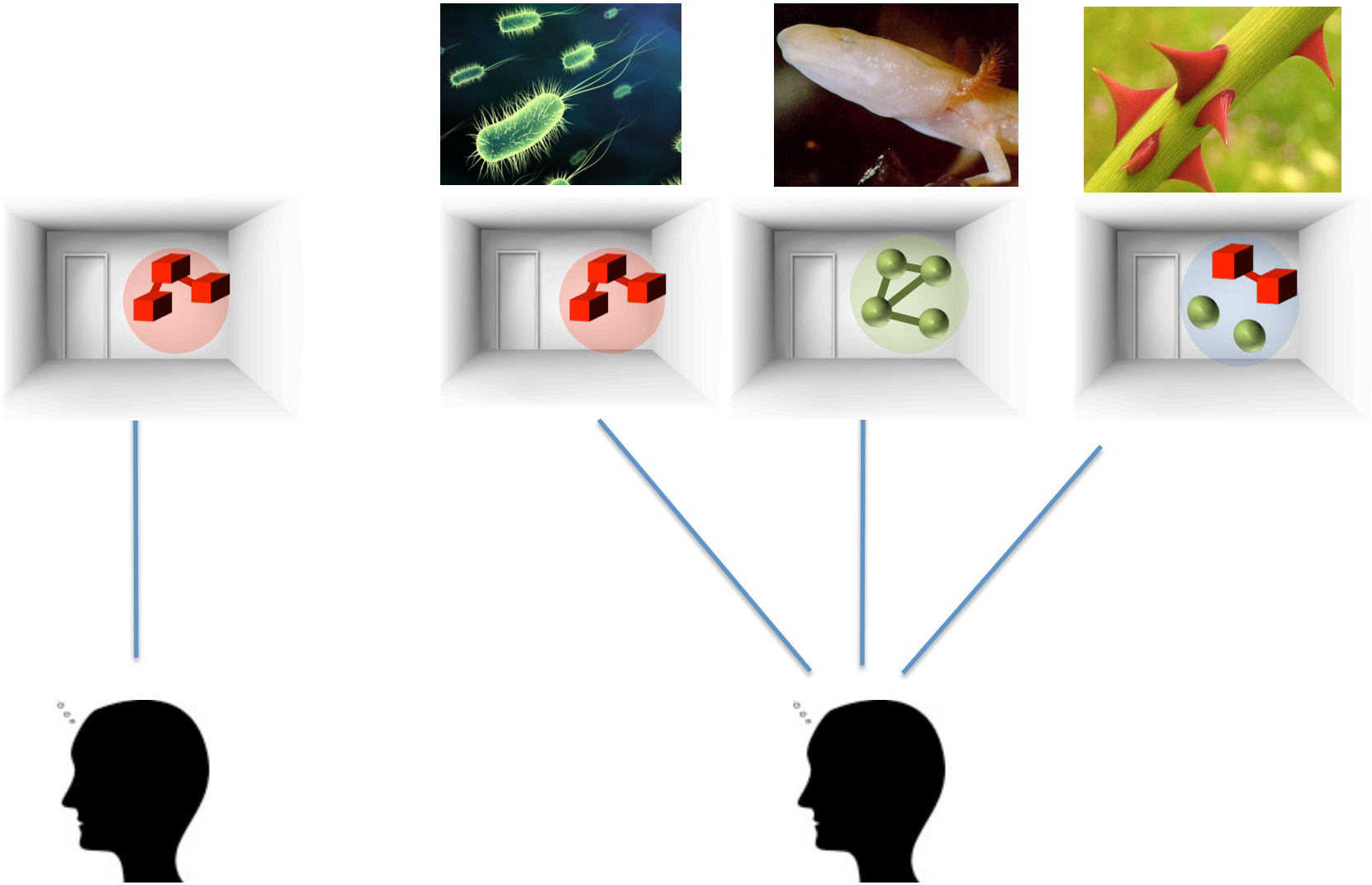


Comparing ACORNS item: cognitive coherence?

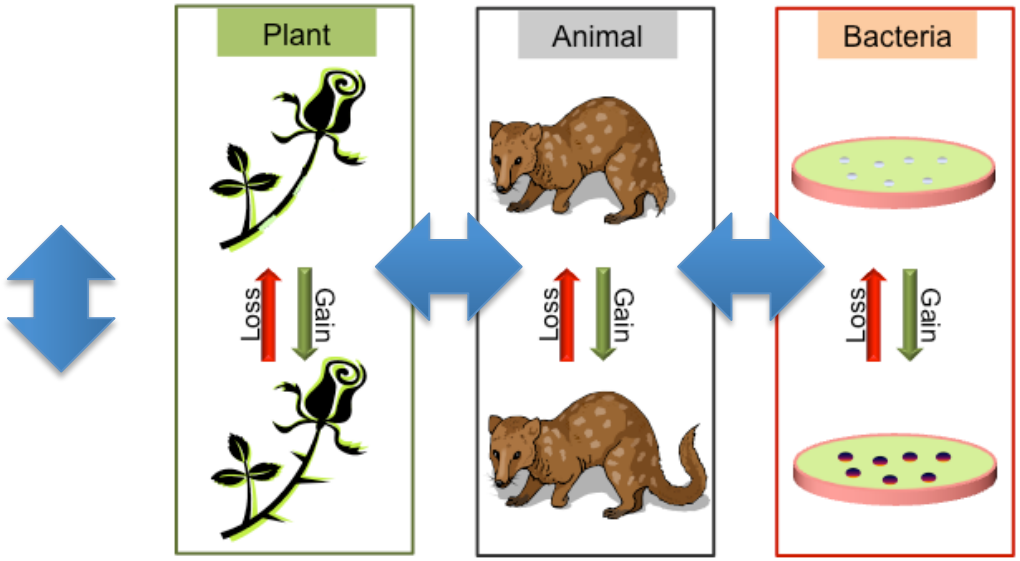
coherence



Comparing ACORNS item: cognitive coherence?

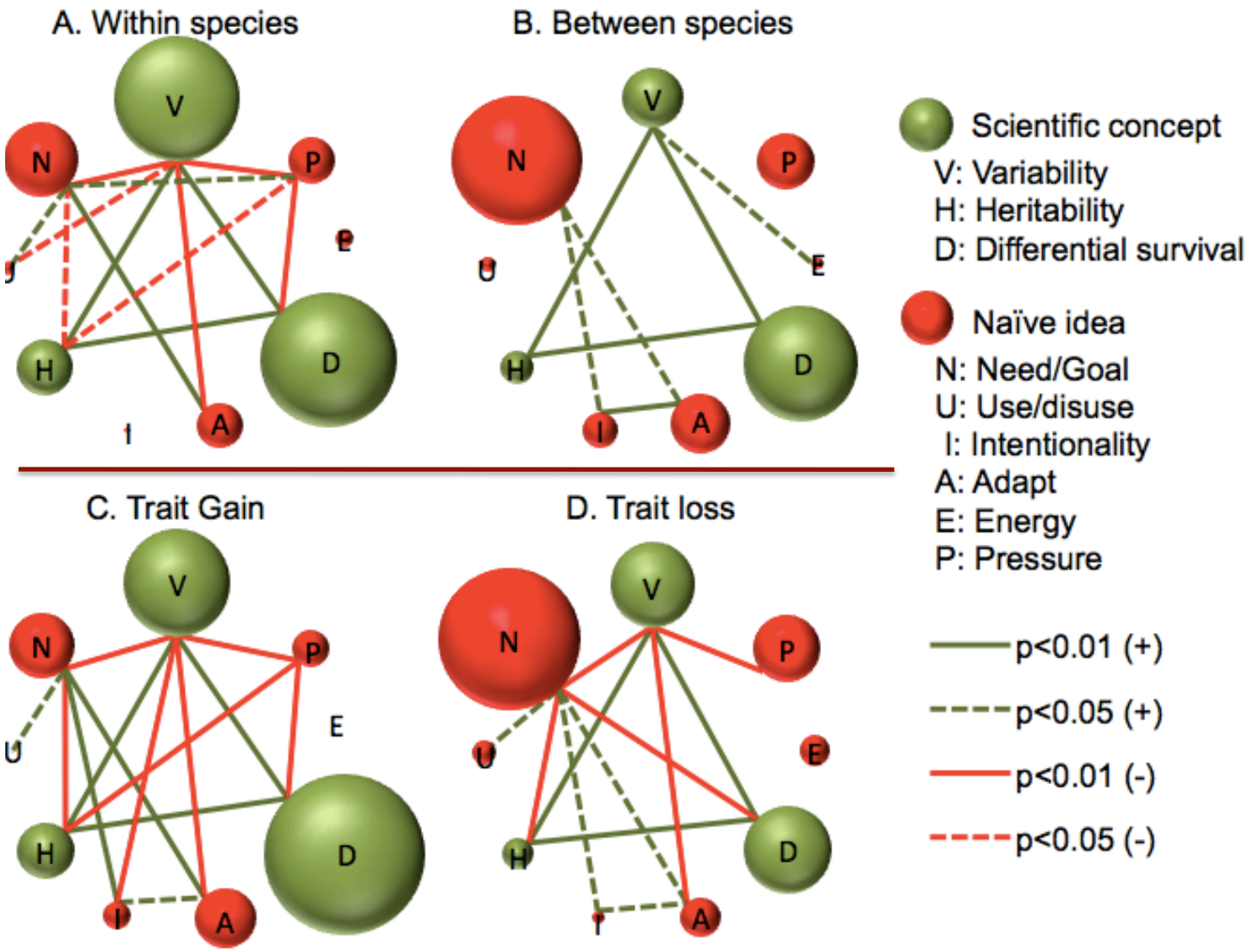


Contexts and evolutionary reasoning



Reasoning bias	Citation
1. Within-vs. between species (+ within)	Nehm & Ha, 2011, JRST, Ha & Nehm 2014
2. Trait gain vs. trait loss (+gain)	Nehm & Ha, 2011, JRST
3. Animal vs. plant (+animal)	Opfer, Nehm, Ha, 2012, JRST
4. Familiar vs. unfamiliar (gender effects)	Opfer, Nehm, Ha, 2012, JRST, etc.

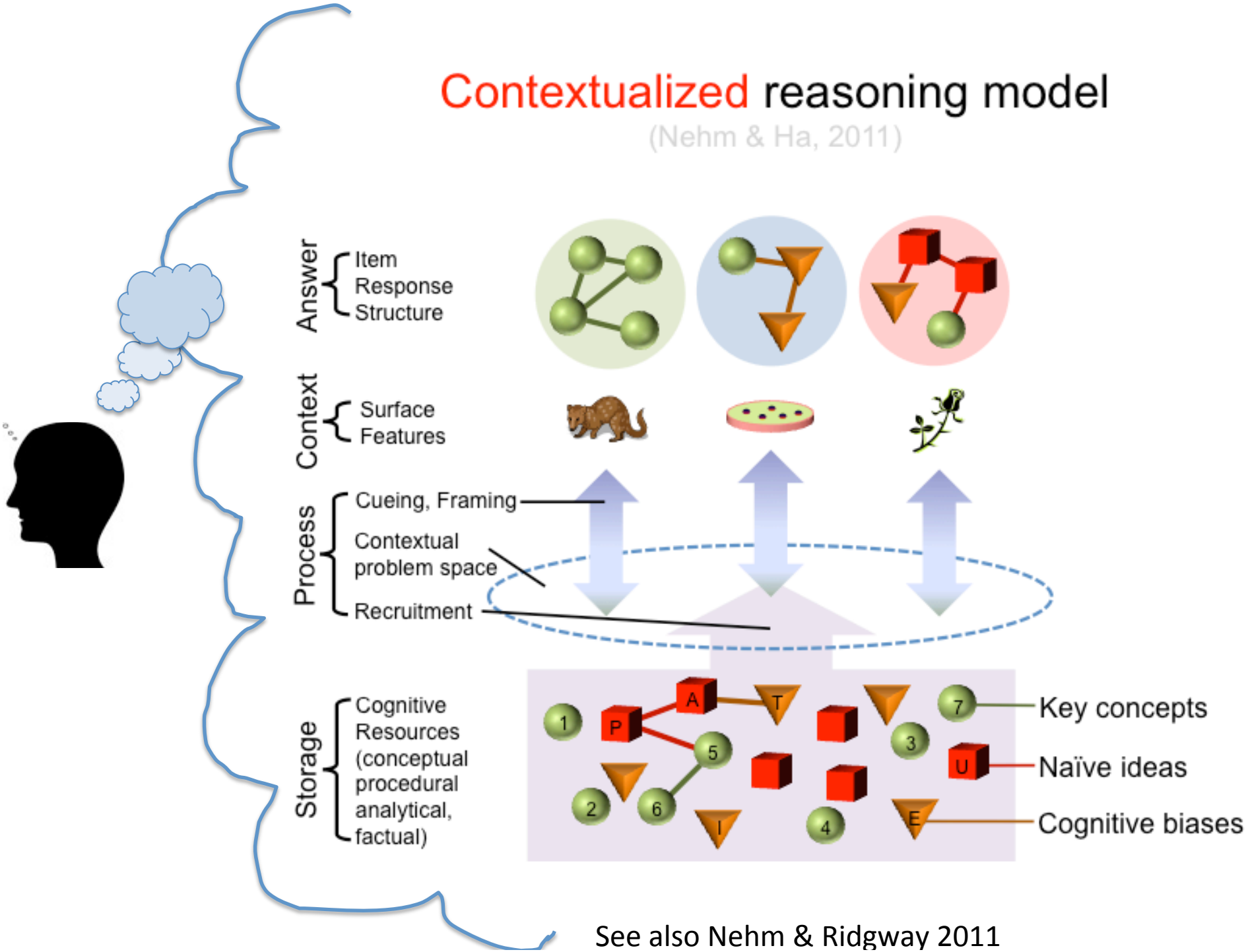
Context: impact on concepts and models in novices



Nehm & Ha (2011)

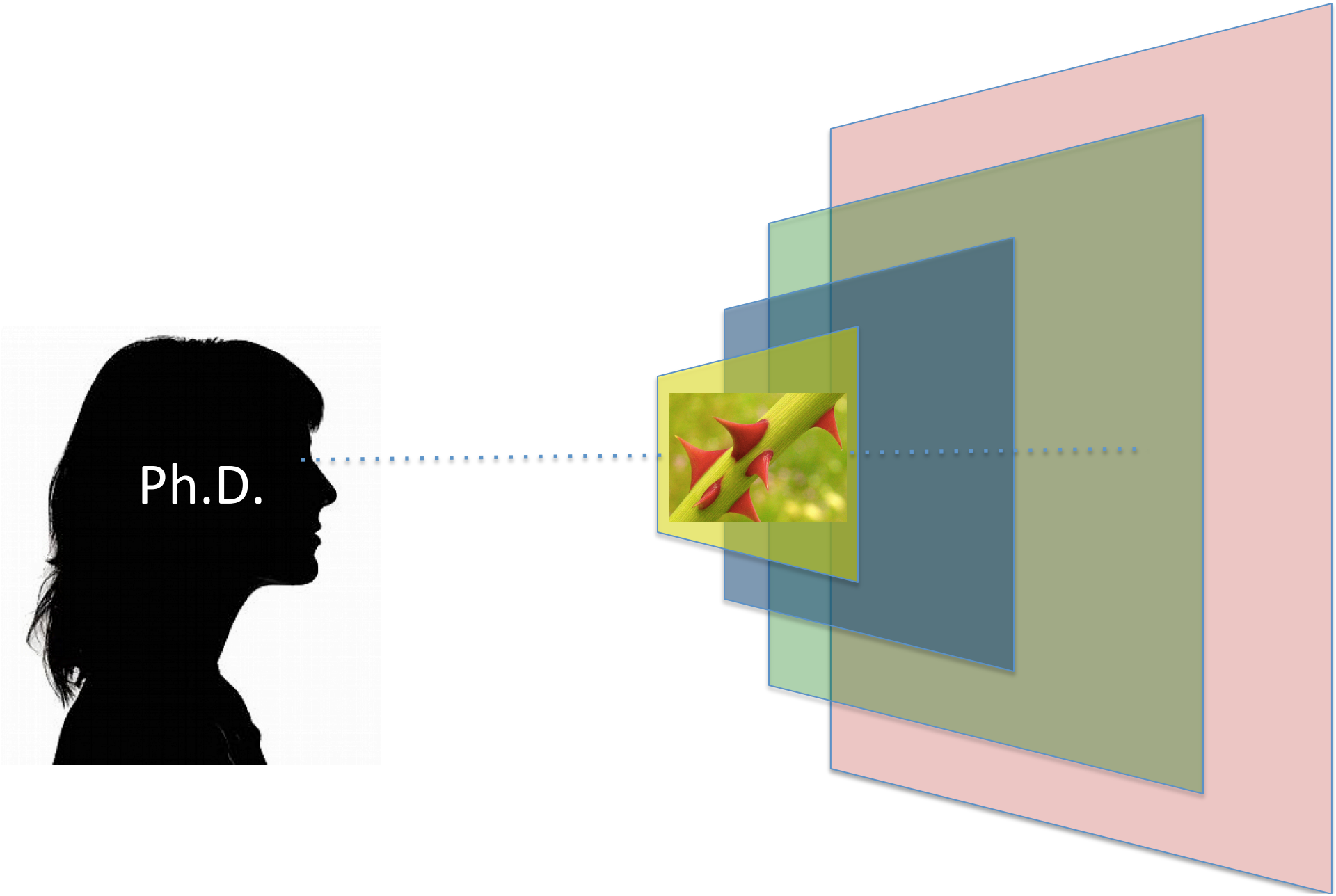
Contextualized reasoning model

(Nehm & Ha, 2011)



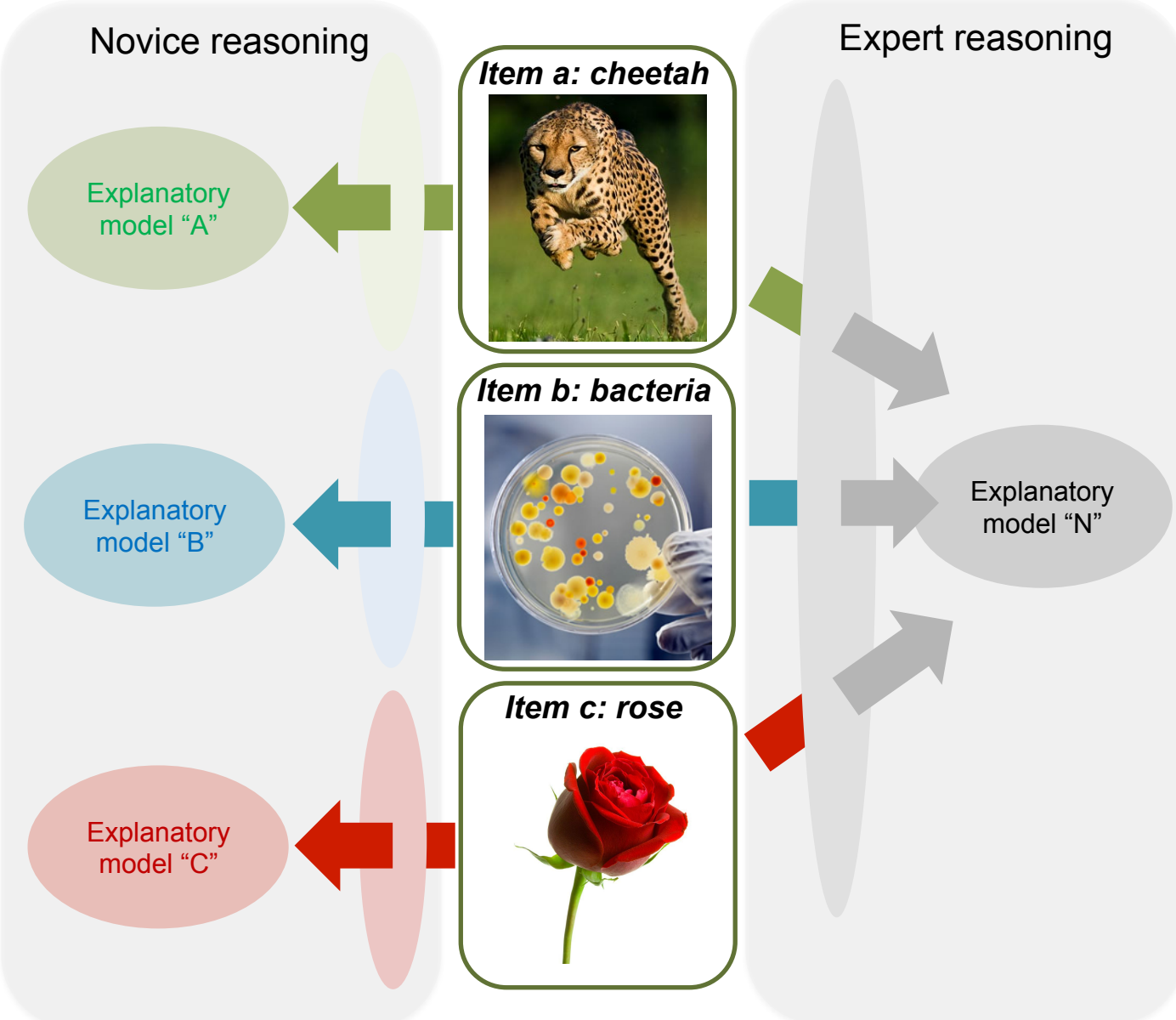
See also Nehm & Ridgway 2011

What about experts (evolutionary biologists?)



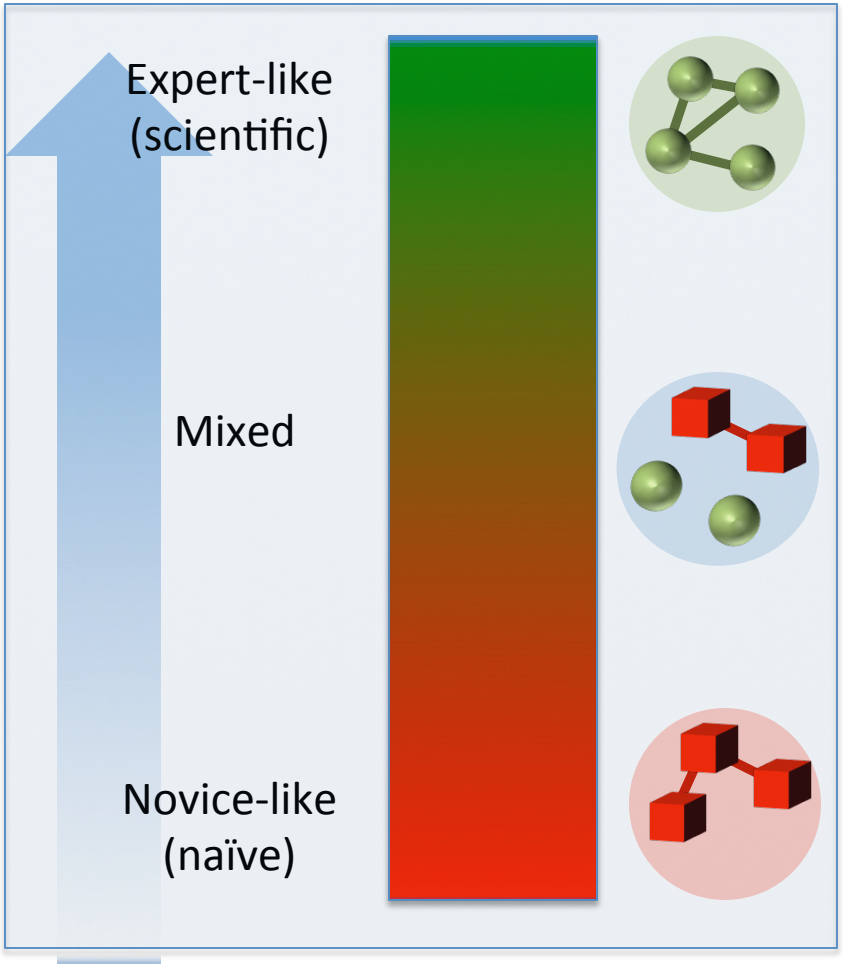
Contexts: novices and experts

- Novices "frame" problems using concrete surface features.
- Experts solve problems using domain principles (e.g., natural selection).
- Significantly greater coherence characterizes experts; multiple explanatory models characterize novices.

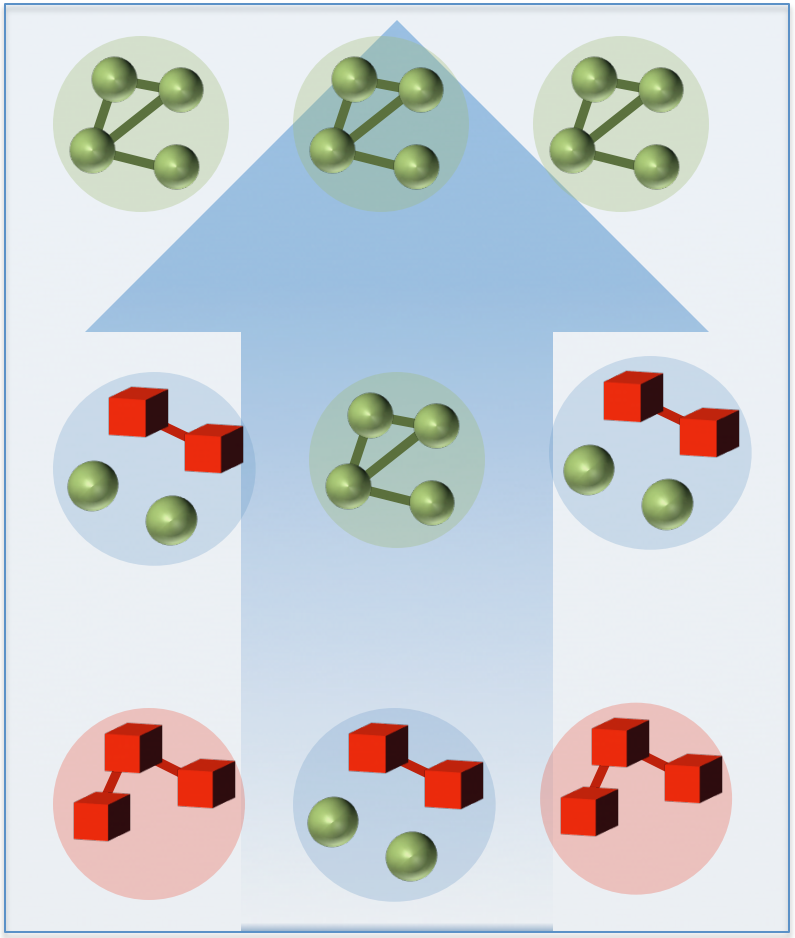


Nehm & Ridgway, 2011

Co-existence, rearrangements of knowledge elements, as expertise grows



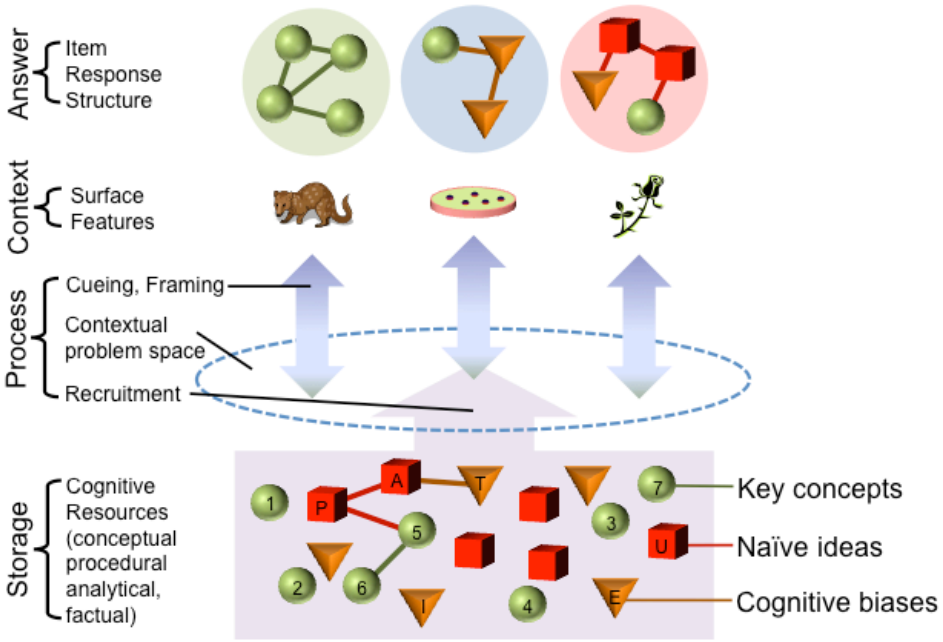
Contextual stability (coherence)



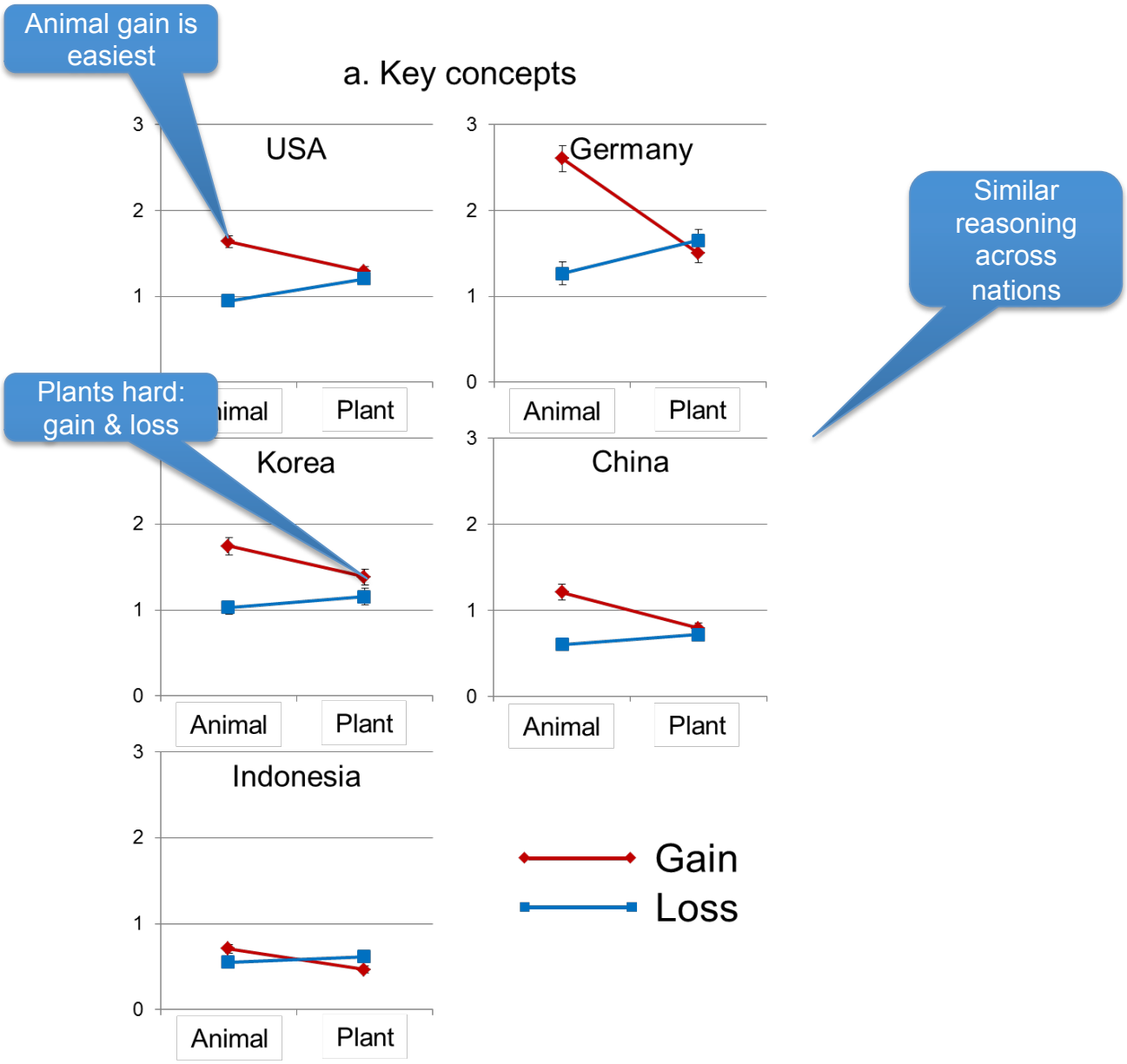
Nehm & Ha, 2011 Journal of Research in Science Teaching

Generalizability of model?

- Studies of several thousand students in Germany, Indonesia, China, and Korea.
- Several years of translation, back-translation, interviews, written assessments.
- Computer and human scoring (Ha, Nehm et al. 2013).

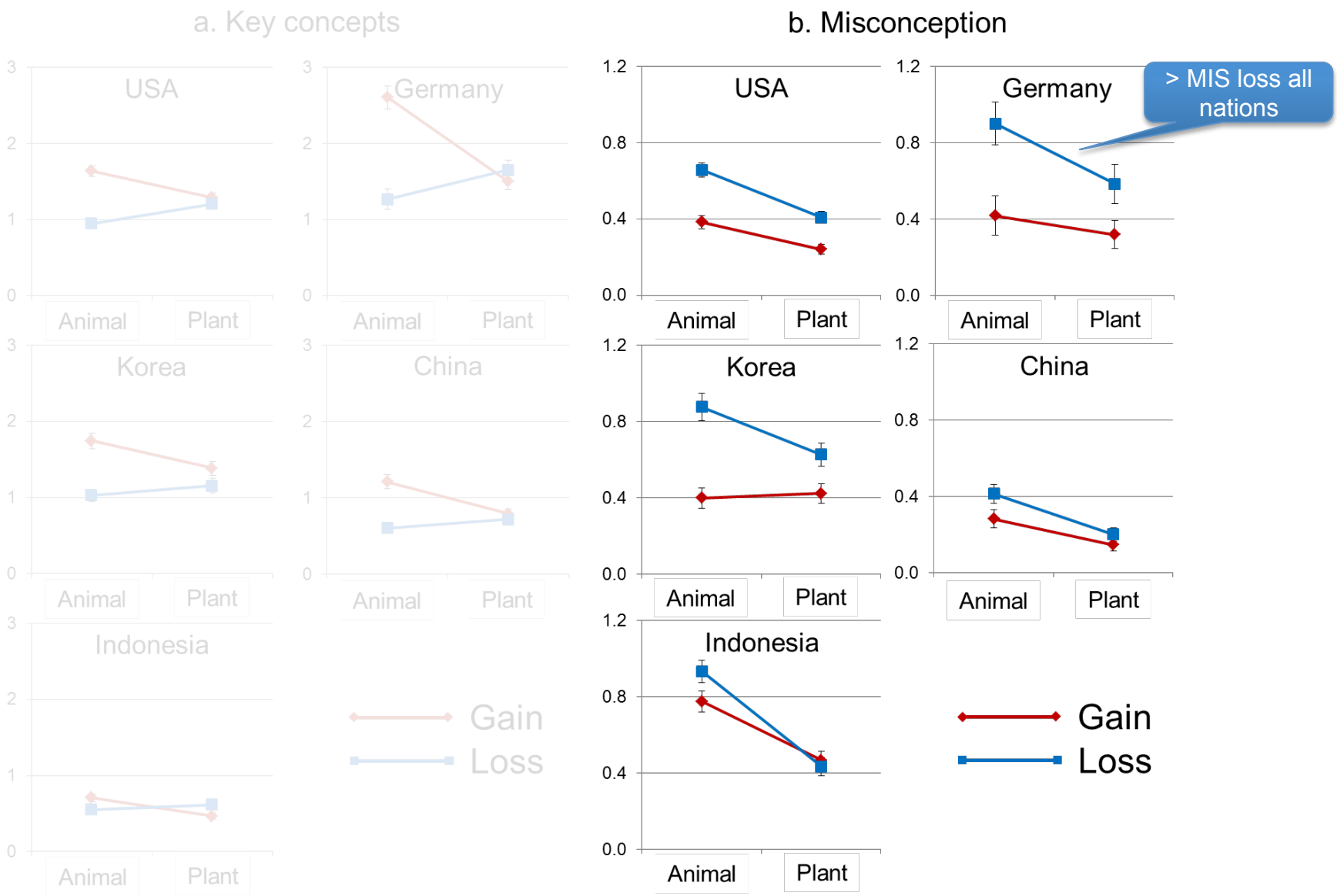


Contexts: Trait gain and loss in animals and plants

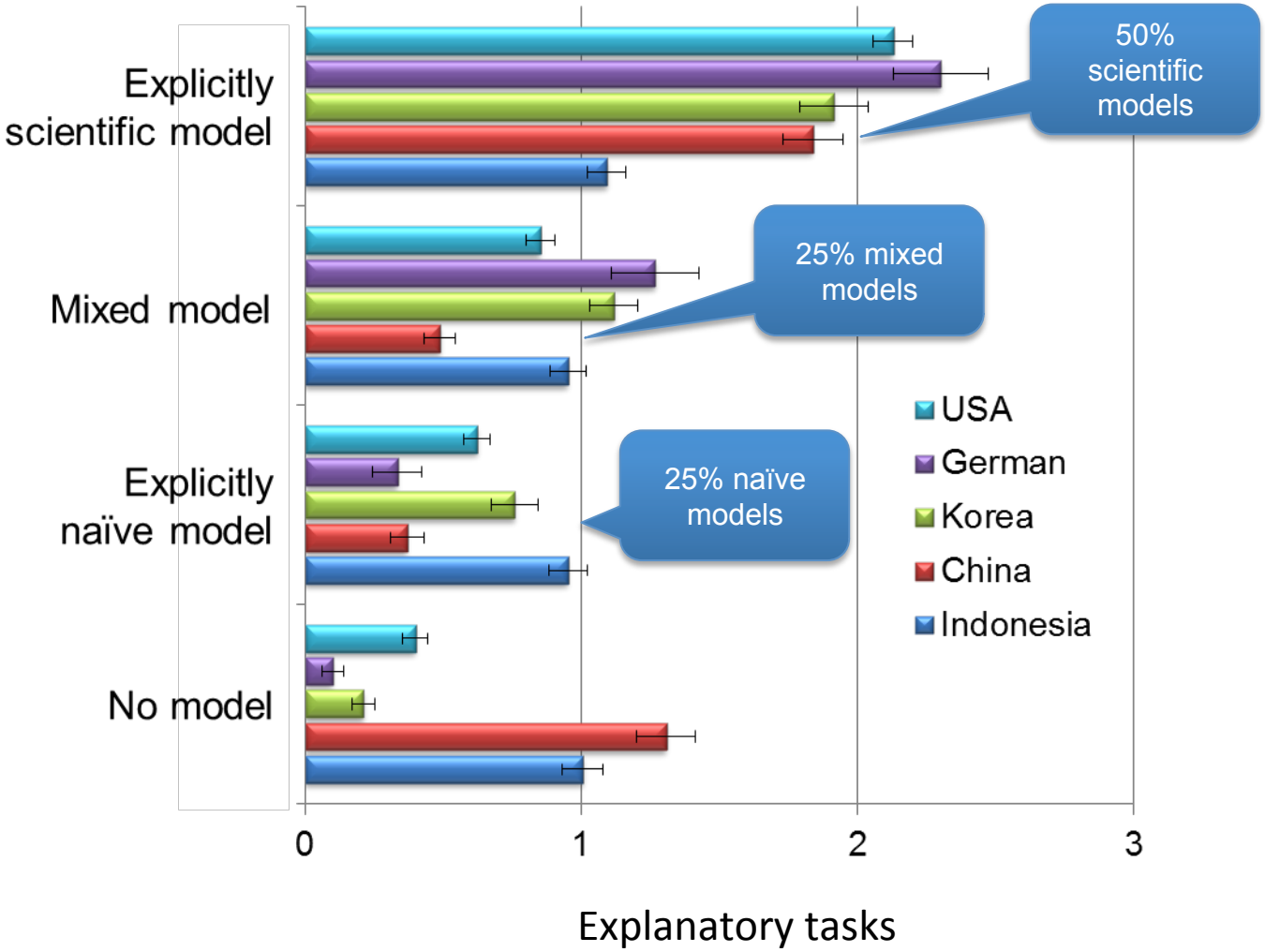


Context effects: naïve (intuitive) ideas

Trait gain and loss in animals and plants



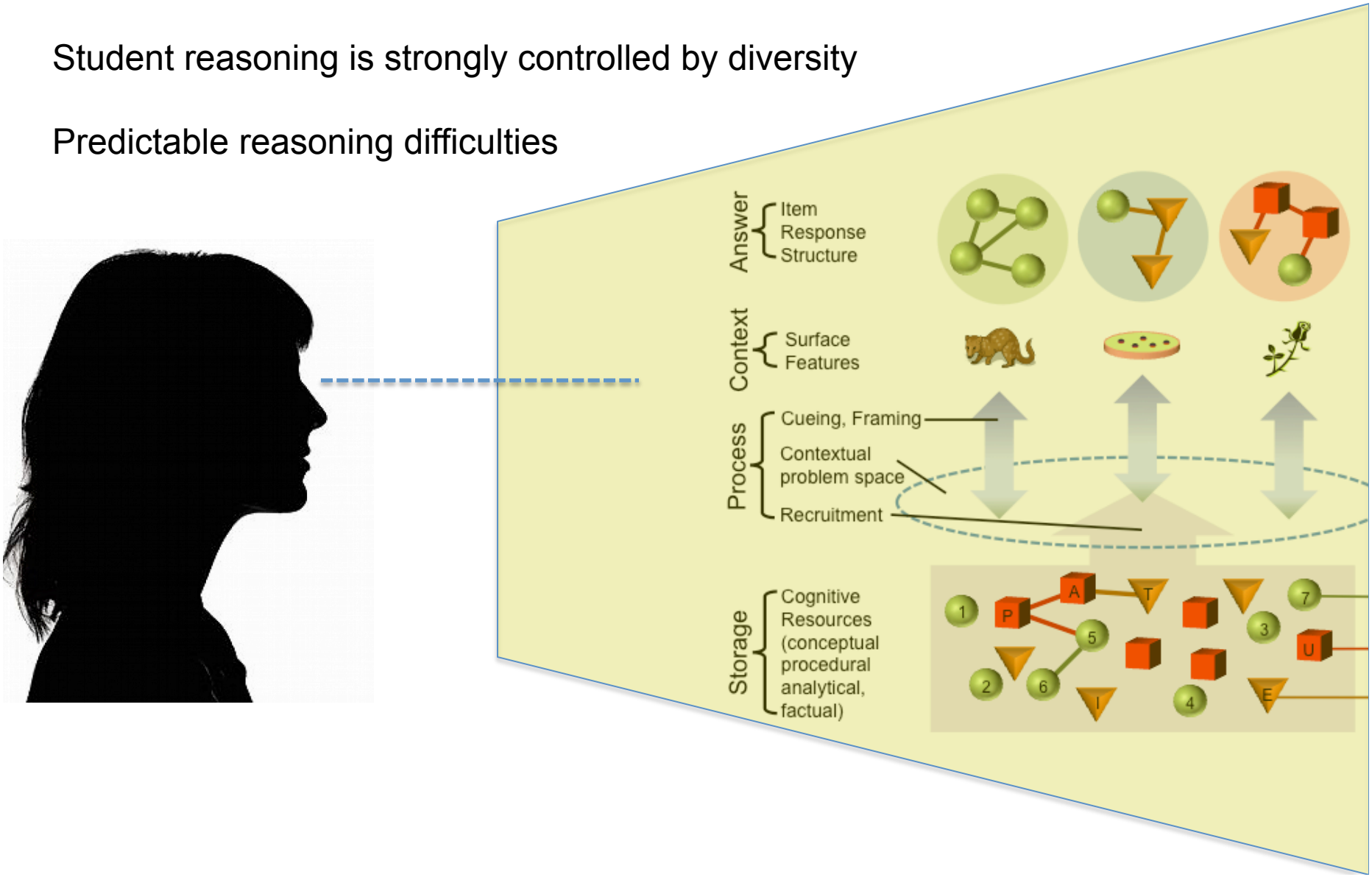
Coherence? Reasoning models across 4 contexts



Thinking about biology

Student reasoning is strongly controlled by diversity

Predictable reasoning difficulties



Contextual learning patterns through time

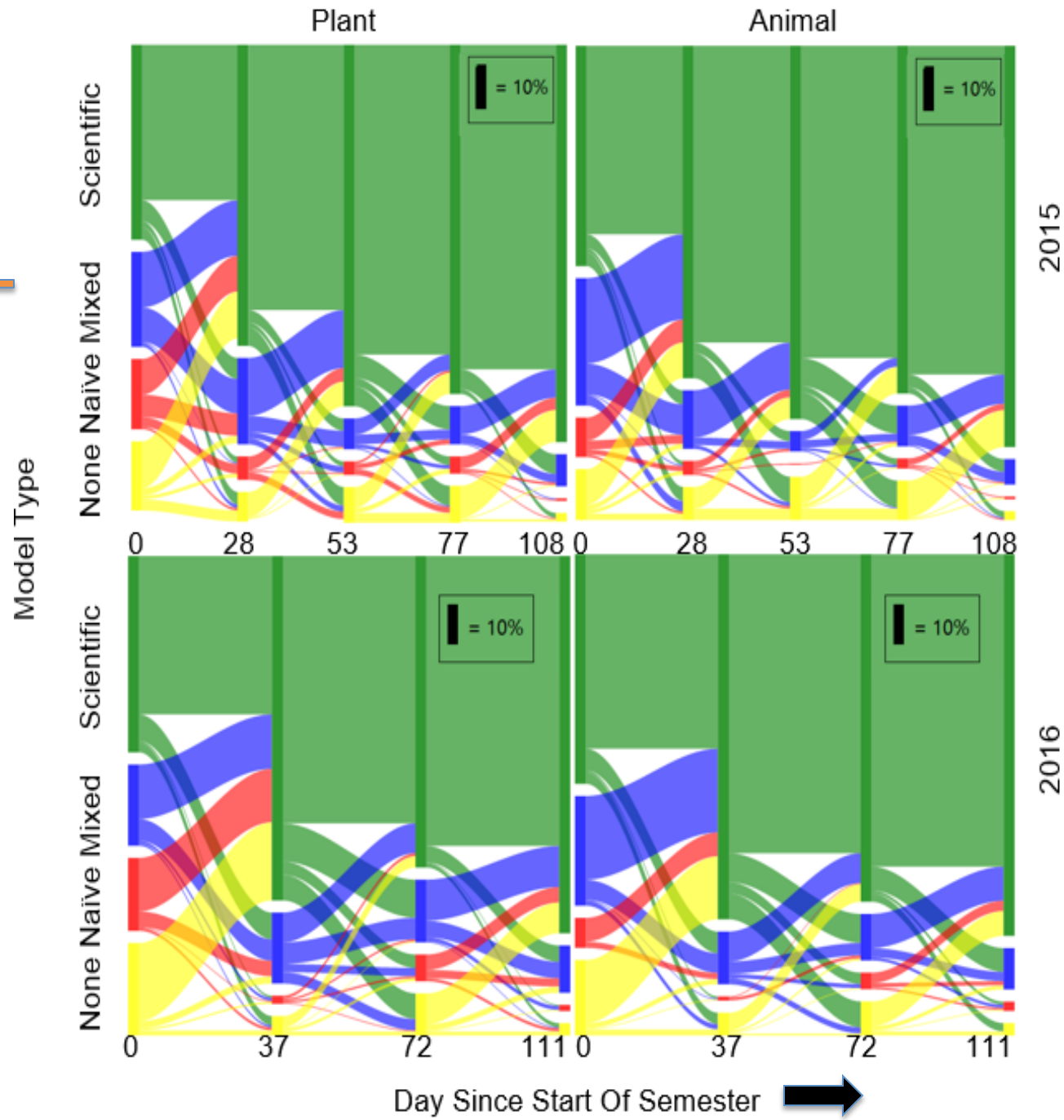
Normative

Mixed

Naive

None

N = 856 students

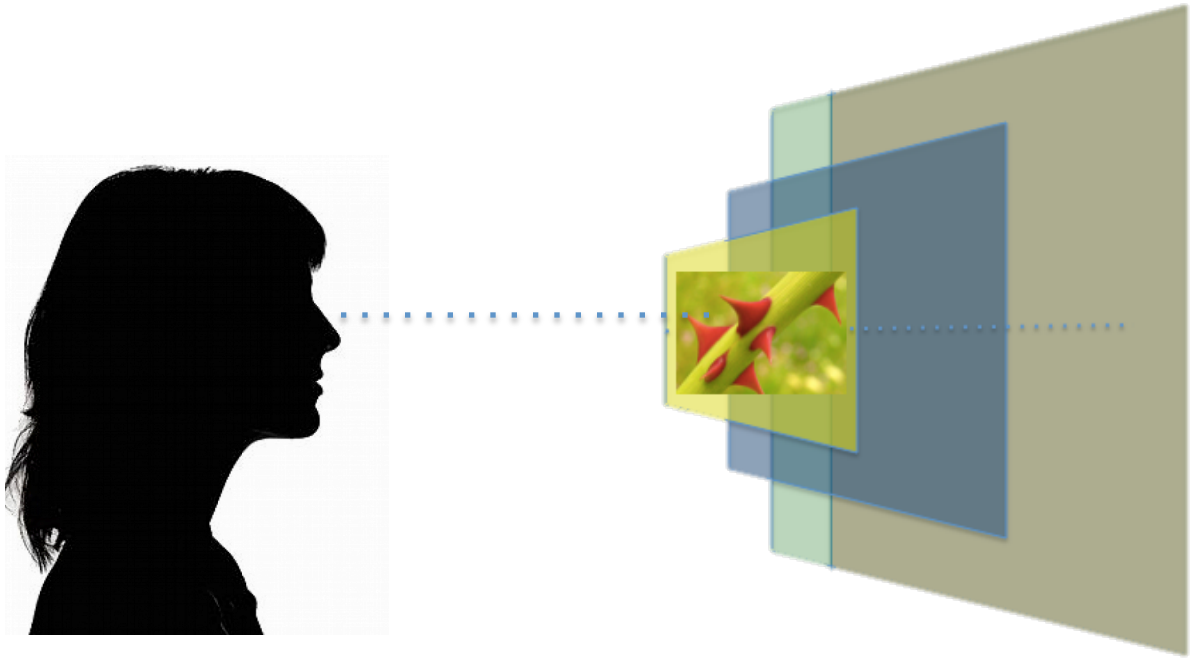


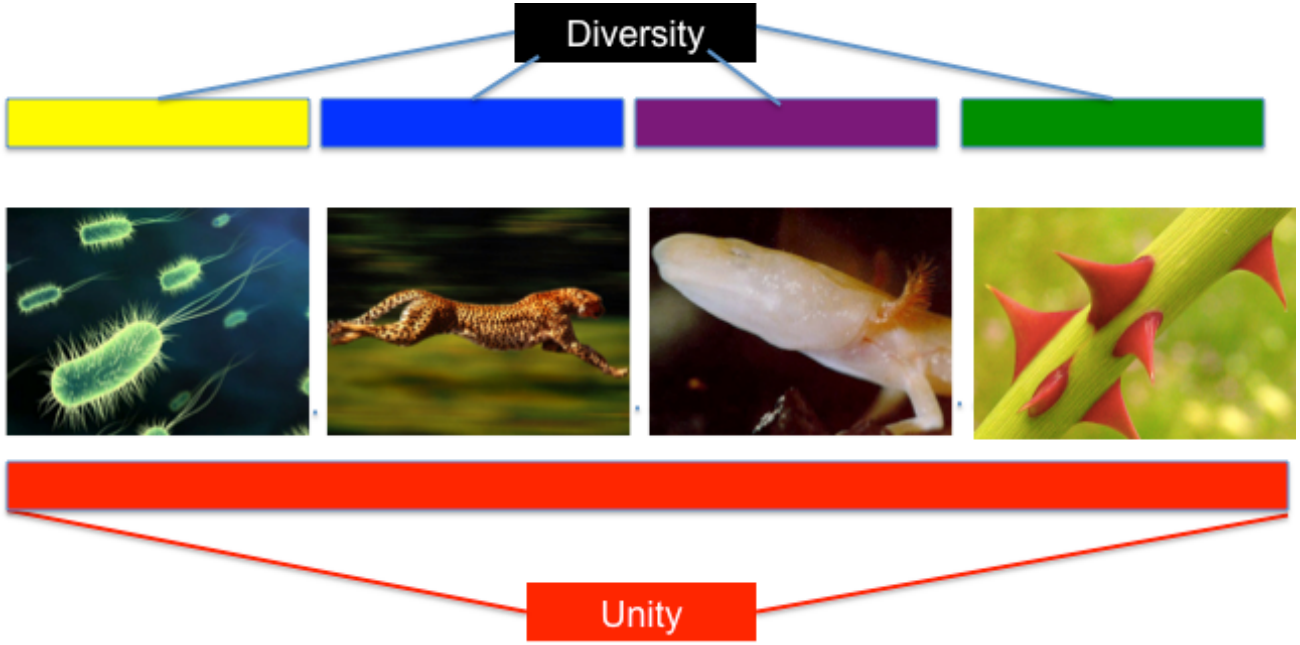
Unity & diversity of life

Source: Wikipedia

Dobzhansky

- How do humans at different educational levels think about biological similarities and differences across scales and contexts?
- What types of causal processes are invoked to explain similarities and differences across biological scales and contexts?




Diversity
Unity

Conclusions

- Biological thinking appears to be conceptually constrained by the type of lineage that is evolving, along with biological scale, polarity, and familiarity;

- Most learners across studies display mixtures of intuitive and scientific resources, not just right or wrong models, and lack cognitive coherence.

- Experts display coherent reasoning using normative concepts—there is no "diversity effect."

Why should we care about these findings?

- Researcher: in a general sense it is important for biology educators to have robust models of how students reason about the diversity of life.

- Curriculum: case studies of particular taxa and traits do not appear to promote coherence; unique models are built for each case.

- Pedagogy: certain contexts predictably elicit naïve (or normative) reasoning; knowing contexts can make teaching more efficient.

- Assessment: without testing students across contexts we can over- or underestimate competency.

Thank you!

Organizers for invitation

US National Science Foundation REESE, CAREER, TUES, EAR programs for funding.

Graduate students and postdocs (Minsu Ha, Meghan Federer, Chad Campbell, Liz Beggrow, Robyn Tornabene) and data collaborators Irvin Schonfeld, Ute Harms, Jorg Grosschedl and John Opfer.