Why Biology Students Have So Much Trouble Using Physics in Biology Classes

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Jacksonville, FL

Recent Reports for Transforming Undergraduate Biology Education

BIO 2010 (2003) focused on curricular issues

- **Interdisciplinary** curricula, with greater emphasis on relevant math, physics, and chemistry
- **Active pedagogies** to better engage students

SFFP (2009) addressed the constraints to curriculum transformation

- **Competencies** rather than **courses**
- Allows **flexibility** in designing curricula

Introduction to UMD BERG

Biology education

Todd Cooke

Kristi Hall

Jeff Jensen

Janet Coffee

Physics education

Joe Redish

Jessica Watkins

Ben Dreyfus

Andy Elby

Overall goals of UMD BERG

- to increase the biological relevance of reformed IPLS sequence at UMD - PHYS 121/122
- to incorporate physical principles into the introductory bio sequence – first BSC1 207
- to develop and evaluate effective strategies for teaching physics in biology classes
- to do research on how biology students learn

We have much to learn from each other!

IPLS at University of Maryland

- PHYS 121/122 – algebra-based IPLS sequence
- Pedagogical and epistemological reforms for over 10 years – Joe Redish and UMD PERG
- Most recent effort – HHMI collaborative project to link together on-going interdisciplinary reform efforts across multiple universities

HHMI Challenge in Life Sciences Undergraduate Education: A Collaborative Project

PURDUE UNIVERSITY

UNIVERSITY OF MARYLAND

UMBC AN HONORS UNIVERSITY IN MARYLAND

UNIVERSITY OF MIAMI

HHMI has asked 4 universities to facilitate the implementation of interdisciplinary curricula for teaching the competencies in *SFFP* report

HHMI Challenge in Life Sciences Undergraduate Education: A Collaborative Project

Some challenges:

- How to design, implement, and assess a competency-based curriculum for training biology students and pre-meds.
- How to measure student learning in this new curriculum.
- How to foster institutional change and national consensus, etc.

UMD’s task – to coordinate to the physics-biology effort.
If interested, contact Joe Redish at redish@umd.edu

Introductory biology challenges

- Biology students are selected for their short-term memories – “binge learning and projectile forgetting”
- Available intro bio teaching materials:
  - Tend to emphasize isolated facts, not broad principles
  - Often start with a major unit on the chemistry of life, but physics of life is scattered as isolated topics (or often unmentioned – e.g., entropy’s role in protein folding)
  - Often describe physical and chemical processes in qualitative terms
  - Tend to promote the maintenance of silo thinking separating different disciplines, as opposed to interdisciplinary thinking

Intro Biology at U Maryland

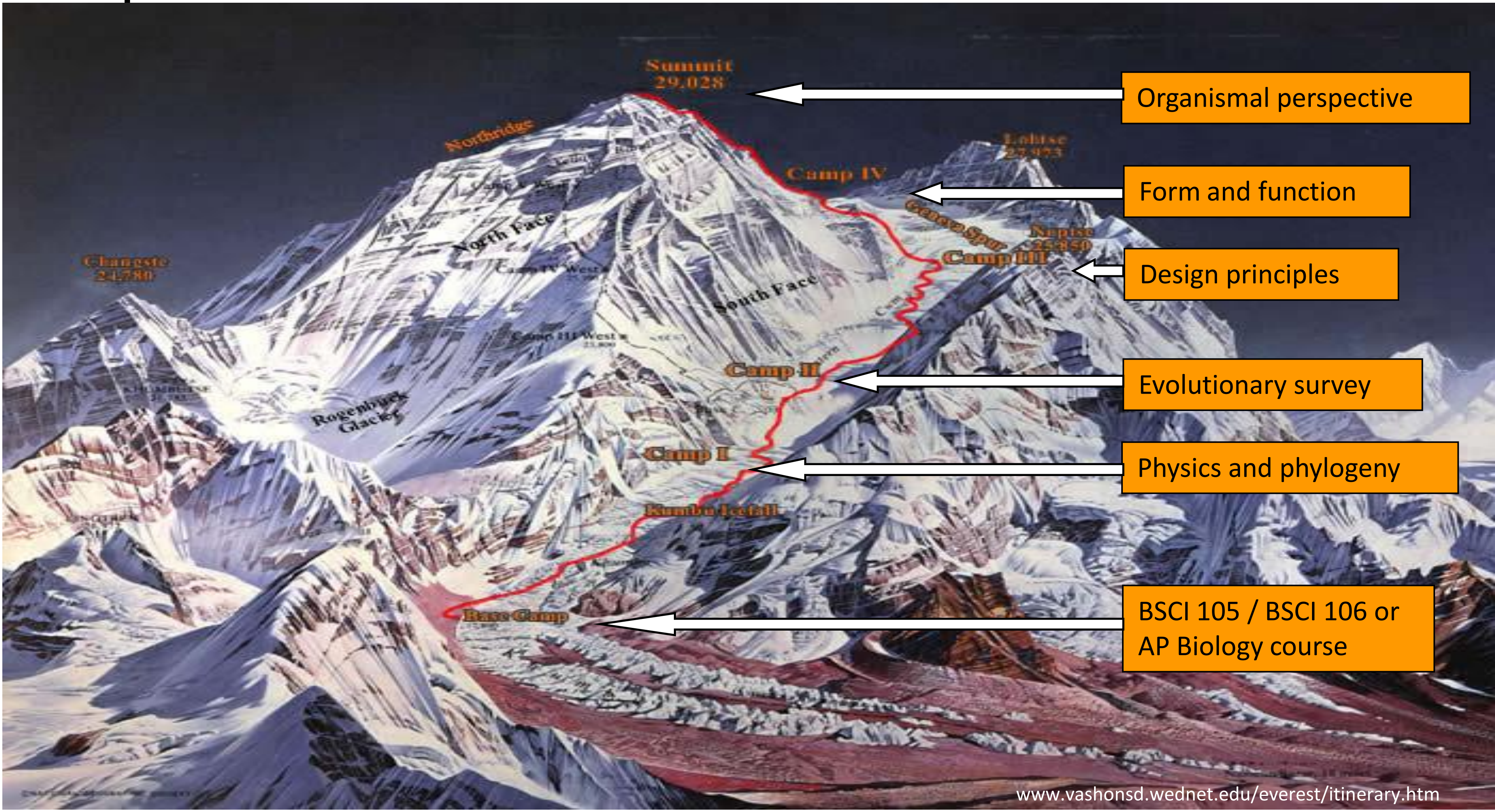
BSCI 105 – molecular and cell biology

BSCI 106 - ecology and evolutionary biology

BSCI 207 – organismal biology - diversity, function, and structure

Conventional approach to organismal biology – "forced march" through the individual phyla and separate units of plant and animal functions

Reformed BSCI 207 Curriculum



- Common physical and chemical principles govern all life & nonlife
- Common genomic heritage of all life (LUCA or LUCAC)
- Unique evolutionary histories for carrying out life’s processes

Revised BSCI 207 curriculum, with conventional lecture pedagogy

- Focus on fundamental principles, including physics
- Unsuccessful efforts to lecture on physical principles - student resistance, limited learning – "why are they trying to teach us physics in a bio class?"
- UMD – BERG efforts – Jessica Watkins, Kristi Hall
  - Evaluate group active engagement (GAE) exercises designed to teach physics principles in biology classes
  - Videotaping lectures and GAE's
  - Conducting one-on-one student interviews
  - Reiterative process of presentation, analysis, and revision

Revised curriculum with conventional lectures -> Persistent problems

- High faculty satisfaction, but most students “revert to wild-type”: short-term cramming and limited deep learning

- Principles viewed as more stuff to memorize, as opposed to using the principles to organize their knowledge into coherent frameworks
- Reluctant to switch from fact acquisition to reasoning from principles
- Struggle to apply their knowledge toward solving new problems
- Limited ability to articulate their knowledge in essay-style exams

In short, the students continued to think like students, as opposed to “thinking like biologists.”

Group active engagement exercises

HHMI/NAS Summer Institute for Undergrad Biology Education – Summer 2009

Thelma/Todd: [stopping suddenly at the edge of a cliff] *What is this?*

Louise/Jeff: *I don't know, I think... I think it's the Grand Canyon (of active engagement)!*

Thelma/Todd: *OK, then listen; let's not get caught.*

Louise/Jeff: *No matter what happens, I'm glad I came with you…. Hey, who locked this door?!*

Group active engagement exercises

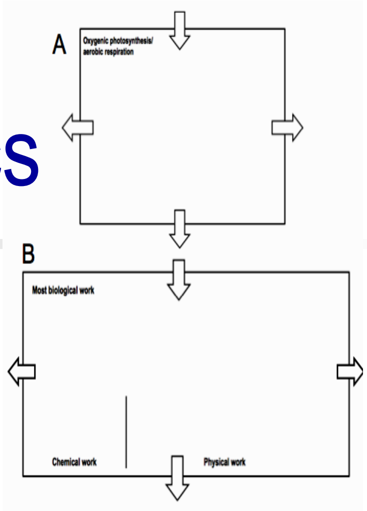
- Replace 1/3 of lecture periods with GAE periods
- Individual working groups composed of 3 or 4 students.
- Focus GAE's on major principles that are not well-conveyed by lectures, as judged from essay answers on previous exams
- Help students use prior bio knowledge to generate mathematical, conceptual, computer, or physical models of these principles
- Create group homework exercises requiring the students to apply these principles toward solving new problems
- Encourage students to discuss the homework problems outside of class, but write up the problems independently of each other.

Group active engagement exercises

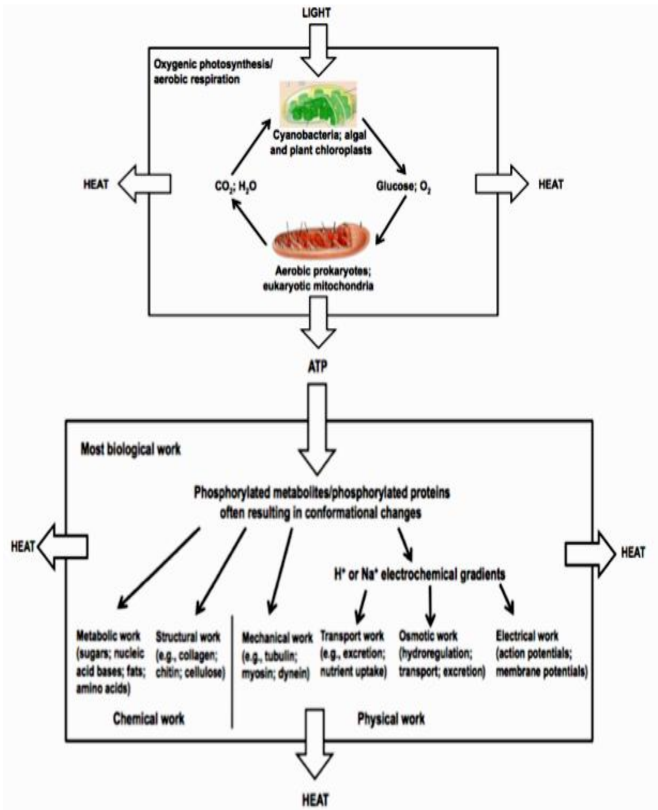
1. Introductory lecture 5 - 10 min
2. Small-group activities 20 - 40 min
   (with intermittent class discussion)
3. Summary class discussion 5 - 10 min
4. Concluding lecture 5 – 10 min
5. Application of principles group homework

Physics GAE’s – thermodynamics, diffusion, fluid flow, biomechanics, scaling

A Complex GAE: Thermodynamics



- Each group used the templates to construct biological energy flow diagrams from a list of terms.
- Class discussion developed consensus diagrams
- Each group identified the general features and operating rules for energy flow in colloquial terms



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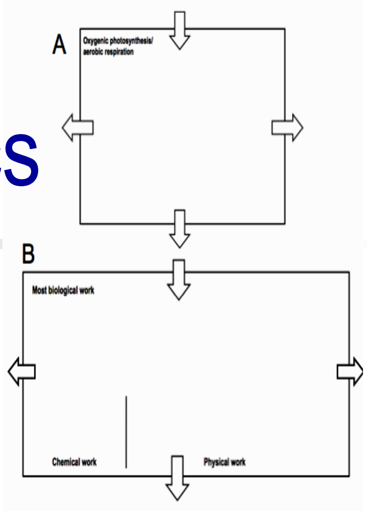
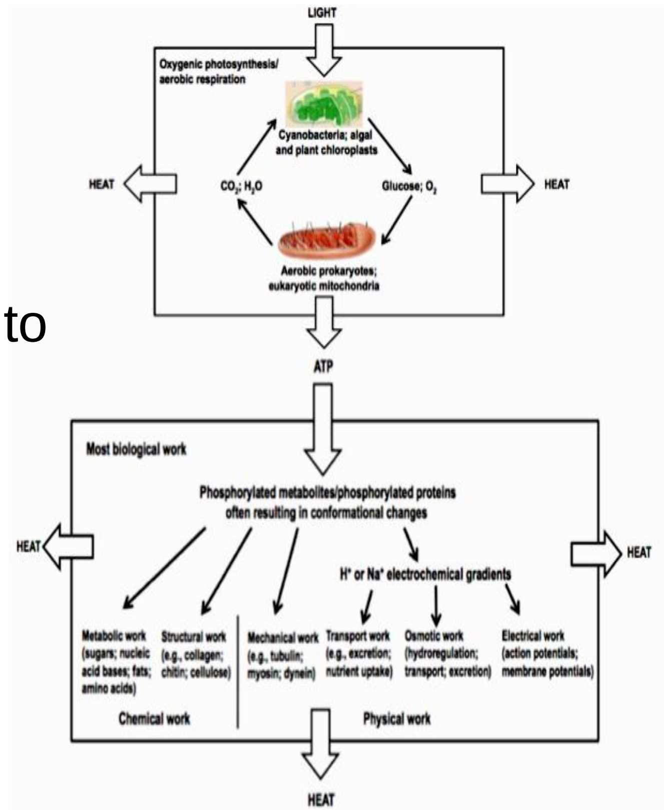
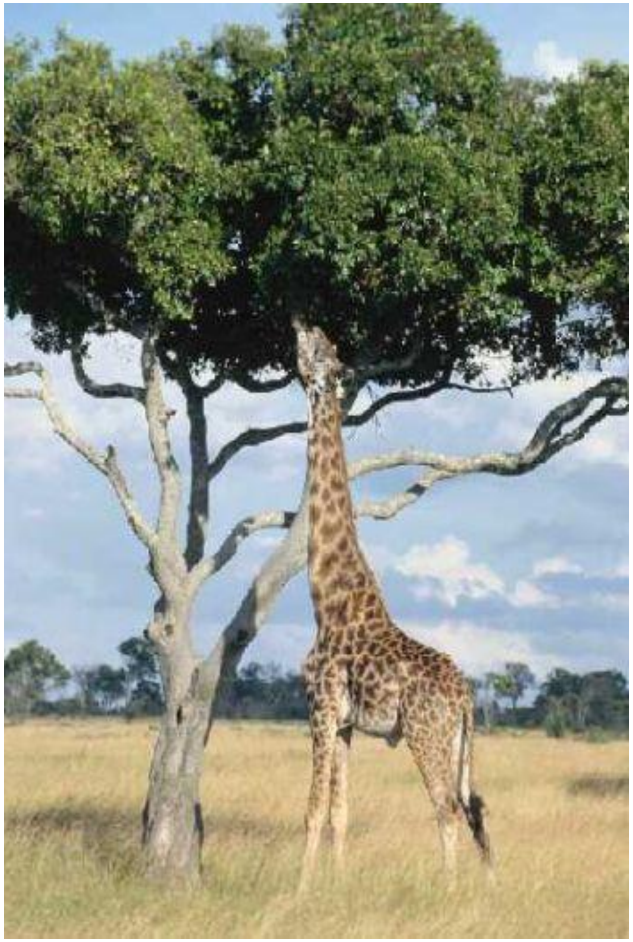


- Class discussion of each group's rules – energy (E) balance and reaction direction rules
- For example, student E balance rules
  - Organisms don't create E, they transform it.
  - Global - Light E flowing into biological world is ultimately equal to heat E leaving it.
  - Each step – the E of initial conditions is equal to the energy of the final conditions.
  - E is not equivalent to biological work.
- Concluding lecture on thermodynamics laws
  - Relate E balance rules to First Law
  - Relate reaction direction rules to Second Law



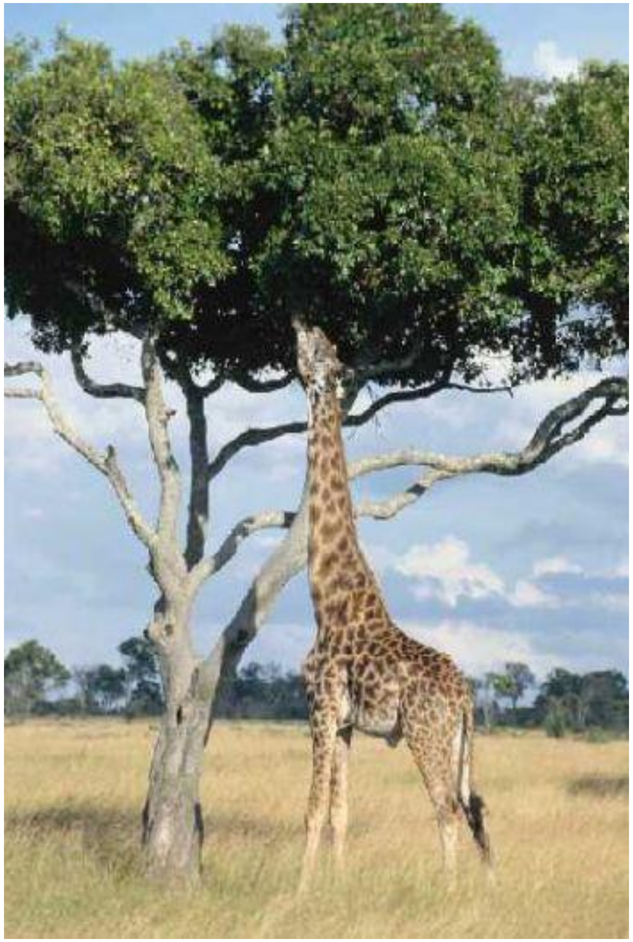
A Simple GAE: Circulatory Systems

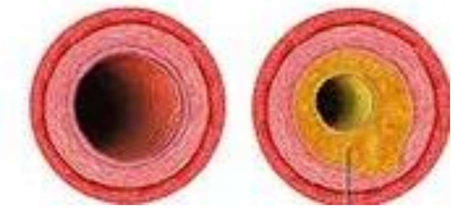
- Into Lecture - brief description of analogous features of mechanical, animal, and plant circulation
- Small group discussion: Which organism has the more powerful pump?
- Class discussion - some groups respond:
  - Giraffe due to its greater flow, OR
  - Acacia due to its greater height
- Small group discussion: How might pressure be related to flow?
- Class – resistance! Class generates of the parameters of Hagen-Poiseuille equation



A Simple GAE: Circulatory Systems

- Hagen-Poiseuille equation - $\frac{V}{t} = \frac{\Delta P}{R}$
- Compare circulation in animals vs. plants
  - Mammals - lower ΔP, much lower R, and much higher V/t as compared to plants
  - Natural selection works on V/t in animals, and ΔP in plants
- Effect of arteriosclerosis – why ΔP increase can't compensate for r decrease





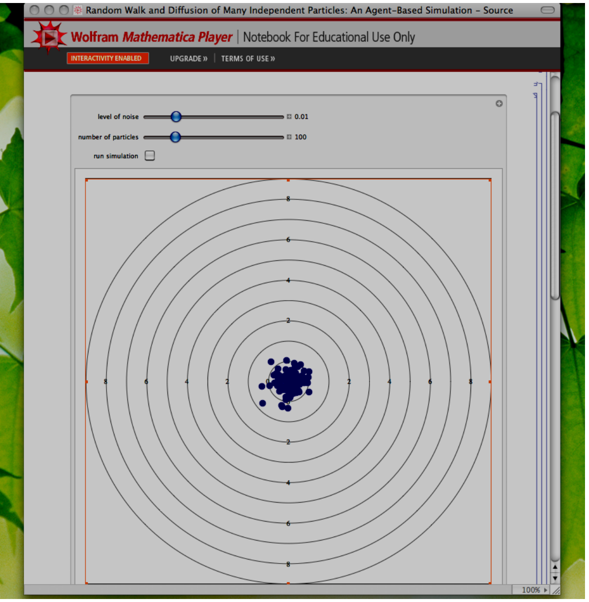
$$R = \frac{8l\eta}{\pi r^4}$$

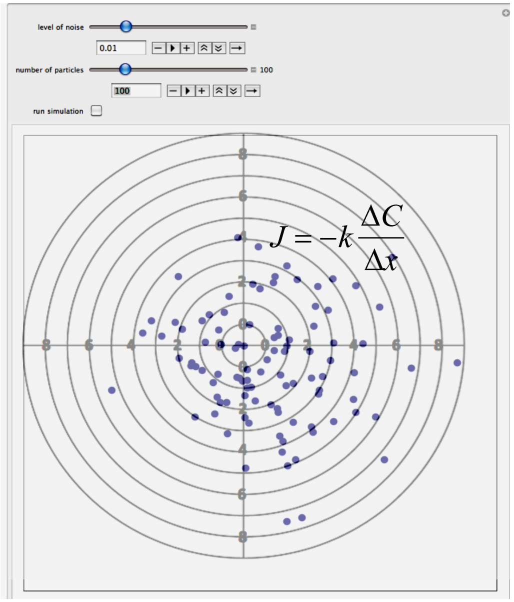
50% occluded artery ⇨ 94% decrease in V/t !!!

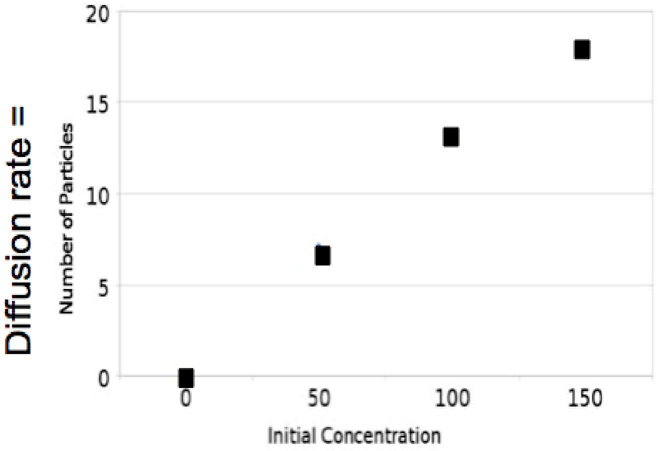
Diffusion GAE

$$J = -D\frac{\Delta C}{\Delta x}$$

- Use modified Mathematica simulations to generate diffusion equations







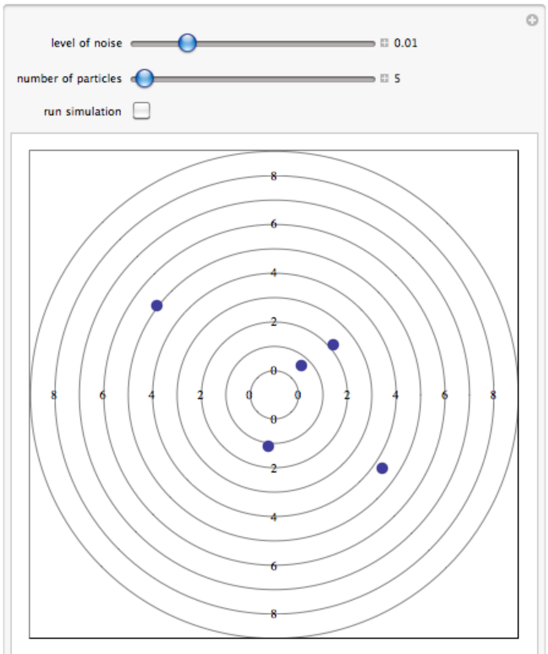
Concentration gradient = $\frac{\text{Concentration difference}}{\text{Distance of 4 circles}}$

- Fick's Law - small groups record the number of particles moving from the center to passing circle #4 and send data to Google docs file
- Students see linear relationship between *J* and $\Delta C/\Delta x$ in class

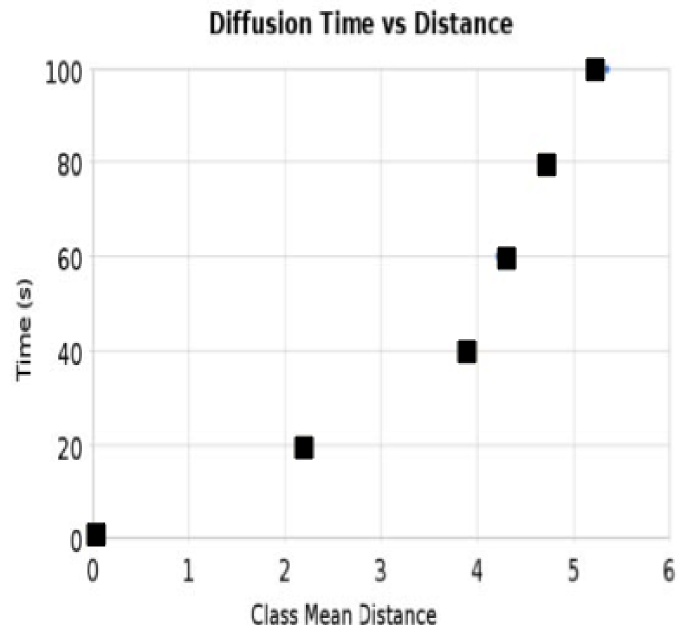
Diffusion GAE

$$t = \frac{\Delta x^2}{2D}$$

- Use modified Mathematica simulations to generate diffusion equations



$J = -$



- Time-to-diffuse equation - small groups record the distance that 5 particles move from circle #0 at various times and send data to Google docs file
- Students see parabolic relationship between *t* and Δ*x* in class

Initial evaluation of pedagogical changes

Classroom videos

Student interviews

Maryland Biology Expectations Survey (MBEX)

Student end-of-semester evaluations

Student exams and grades

Standard university on-line student reviews

Student Feedback in BSCI 207 – same instructors from traditional to reformed

Standard UM survey questions	Mean score on Likert scale		
	S 2008 lecture only	S 2009 clickers	S 2010 GAE's
The course was intellectually challenging	4.21	4.45	4.59
I learned a lot from this course	3.77	4.02	4.23
The instructor helped create an atmosphere that kept me engaged in the course	3.91	4.15	4.45
Overall, this instructor was an effective teacher	4.22	4.36	4.49
How much effort did you put into this course? (little/moderate/considerable)	9/38/53	4/50/46	2/25/74

Likert scale – 1=strongly disagree; 2=disagree; 3=neutral; 4=agree; 5=strongly agree

Initial results – reformed BSCI 207

MBEX results: biology and math/physics

Using mathematics to explain biological phenomena is more confusing than helpful to students.

Initial results – pre and post responses

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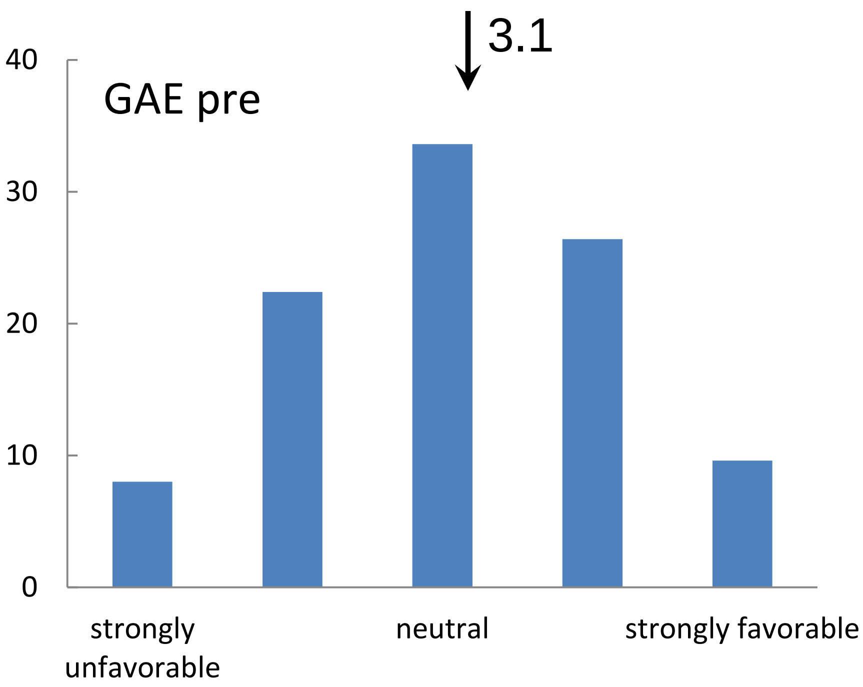

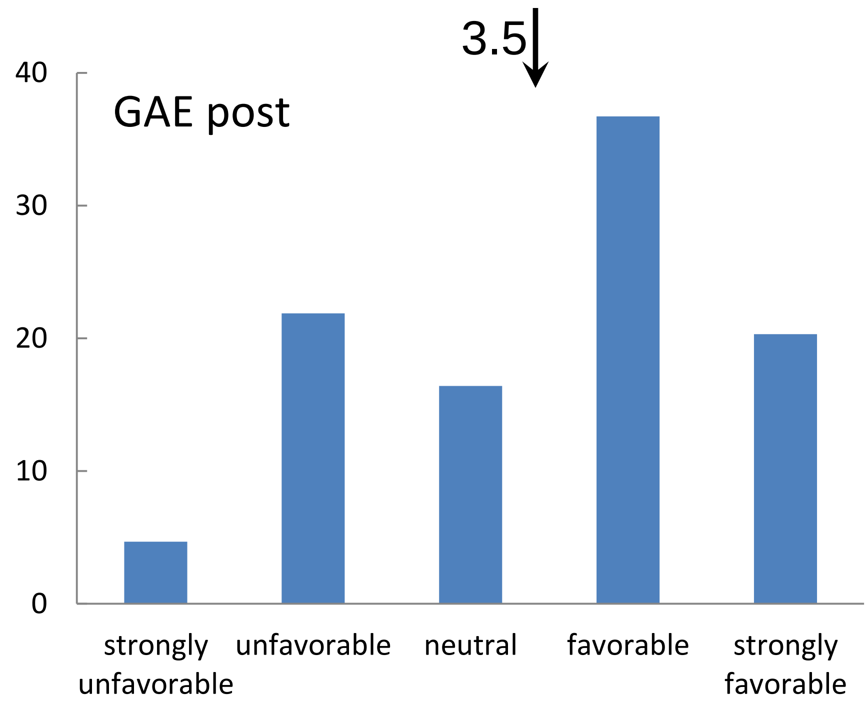

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MBEX results: biology and math/physics

Biology and physics are:

A. Related to each other by common principles.
B. Separate and independent of each other.

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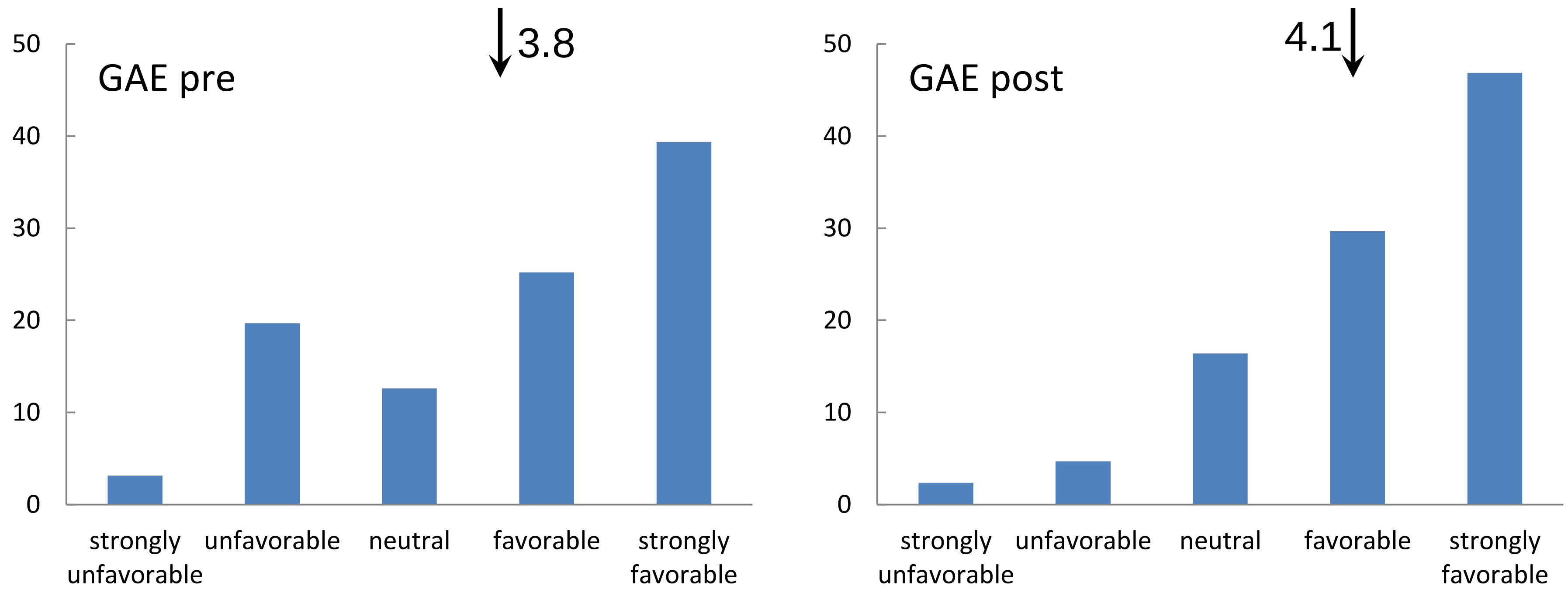

Tentative interpretations

1. Relevant physics can be successfully taught in an introductory biology class using active-engagement pedagogy.
2. Biology teachers at UM have benefited greatly from the conceptual and pedagogical advice from our IPLS colleagues.
3. It is hoped that these biology students will maintain persistent favorable attitudes toward physics into their IPLS courses.
4. In our experience, meeting the challenges of *BIO 2010* and *SFFP* in both introductory biology and IPLS classes requires effective collaborations between physicists and biologists.
5. Incidentally, it has been a lot of fun working together!

Initial results of pedagogical reforms

MBEX results: facts or principles?

I expect my exam performance in biology courses to reflect how well I can:

A. Recall course materials the way they are presented in class.
B. Apply course materials in situations not discussed in class.

Initial results – lecture only BSCI 207

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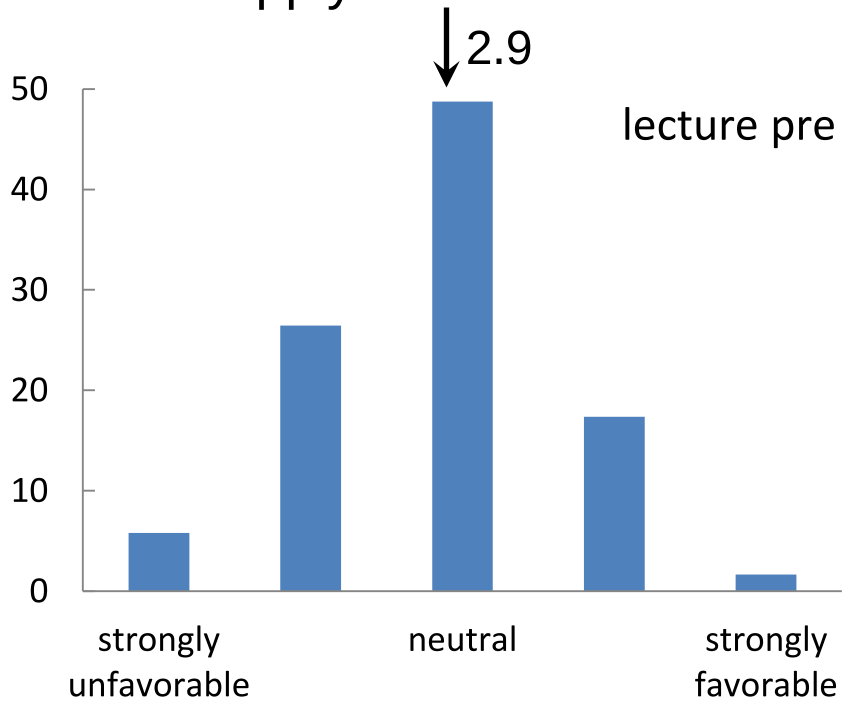

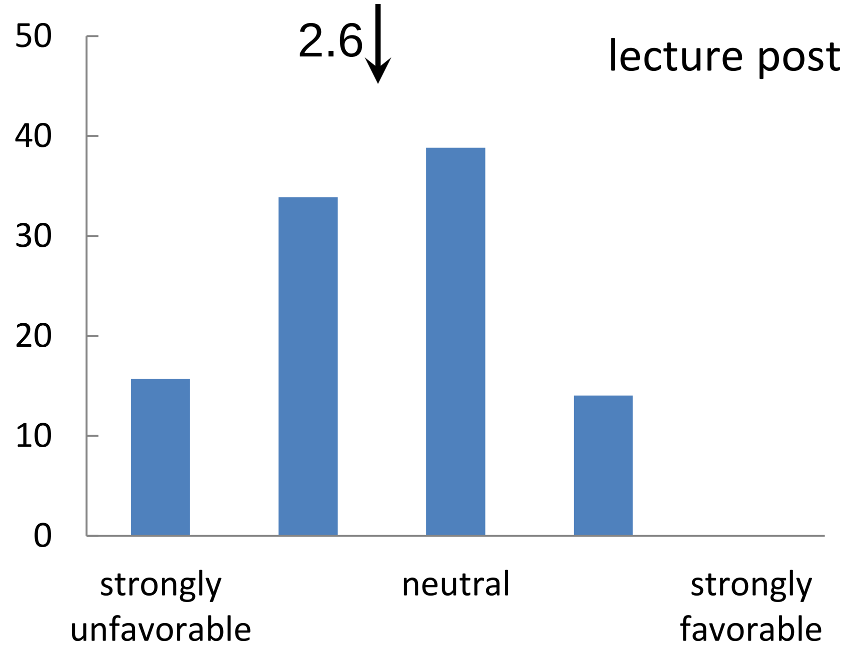

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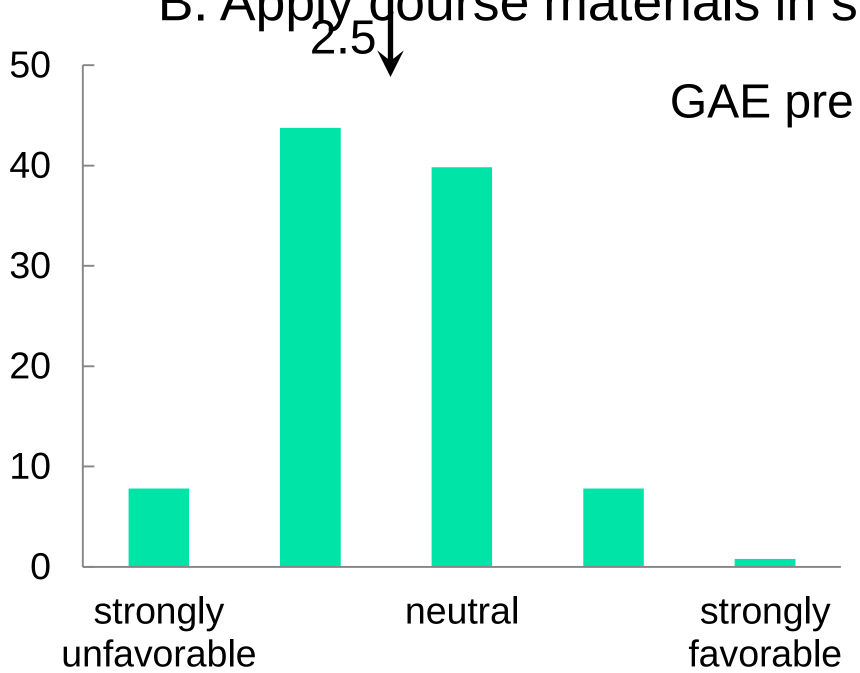

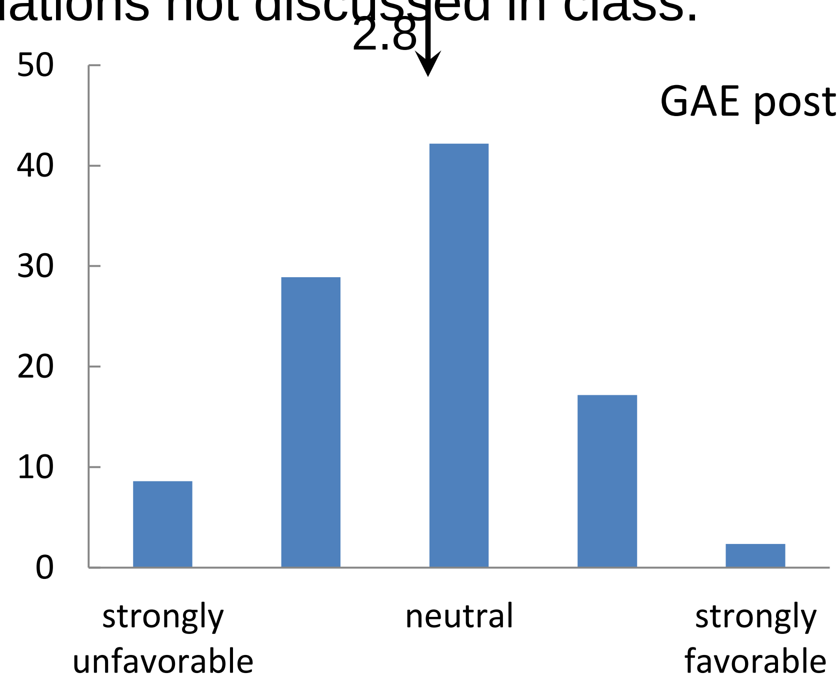

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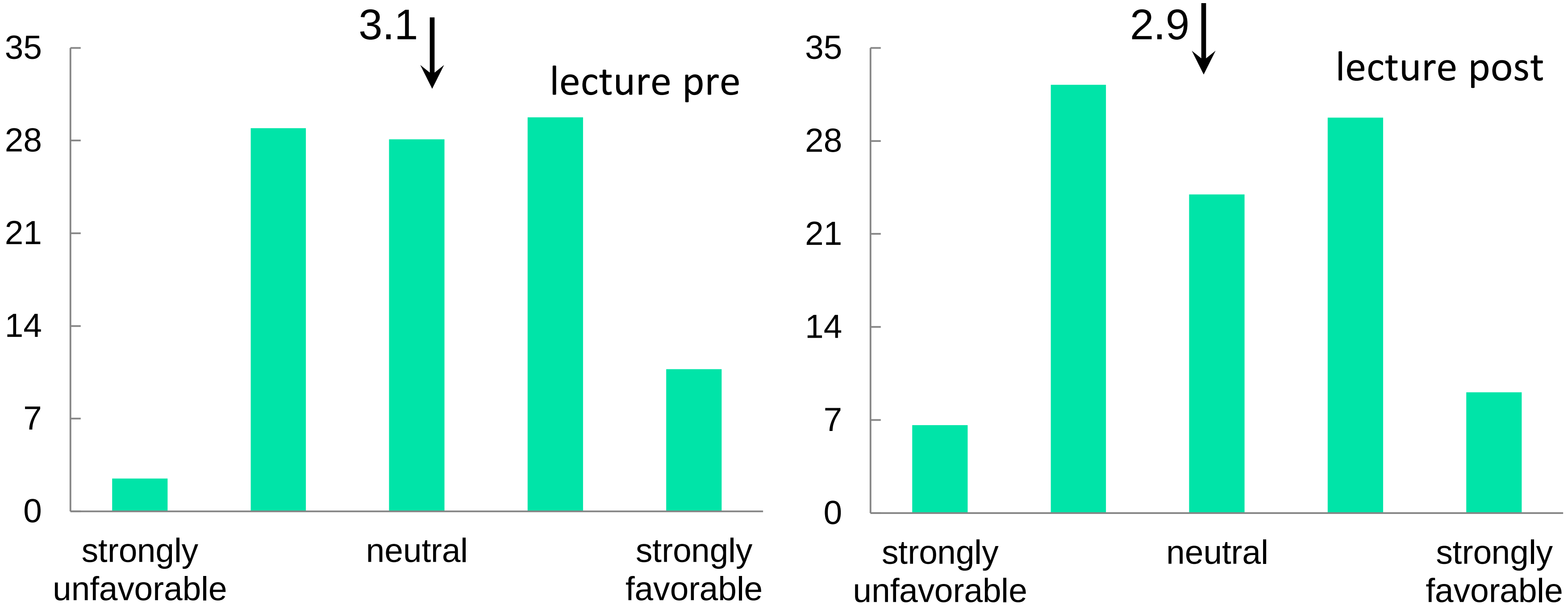

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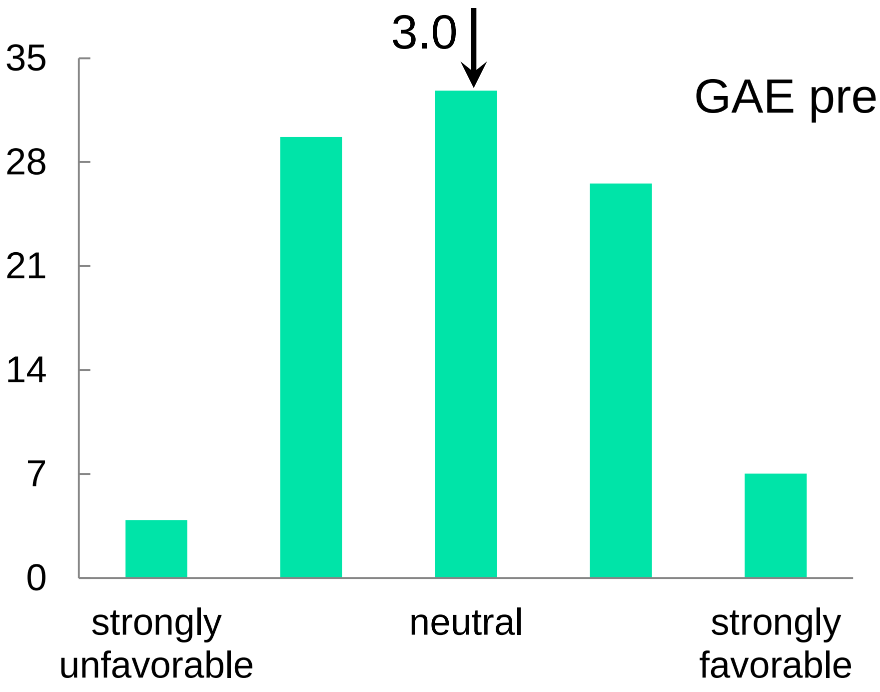

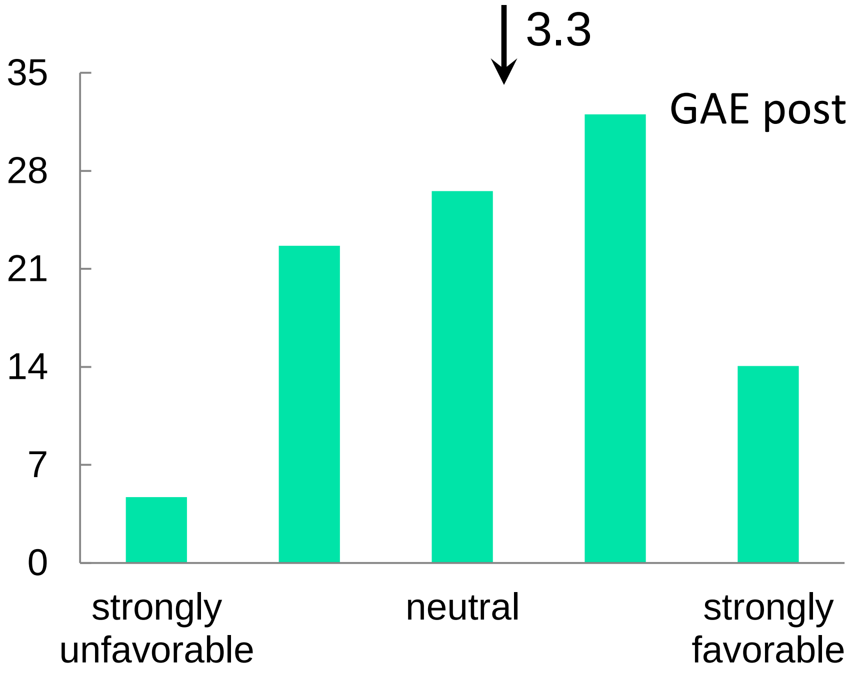

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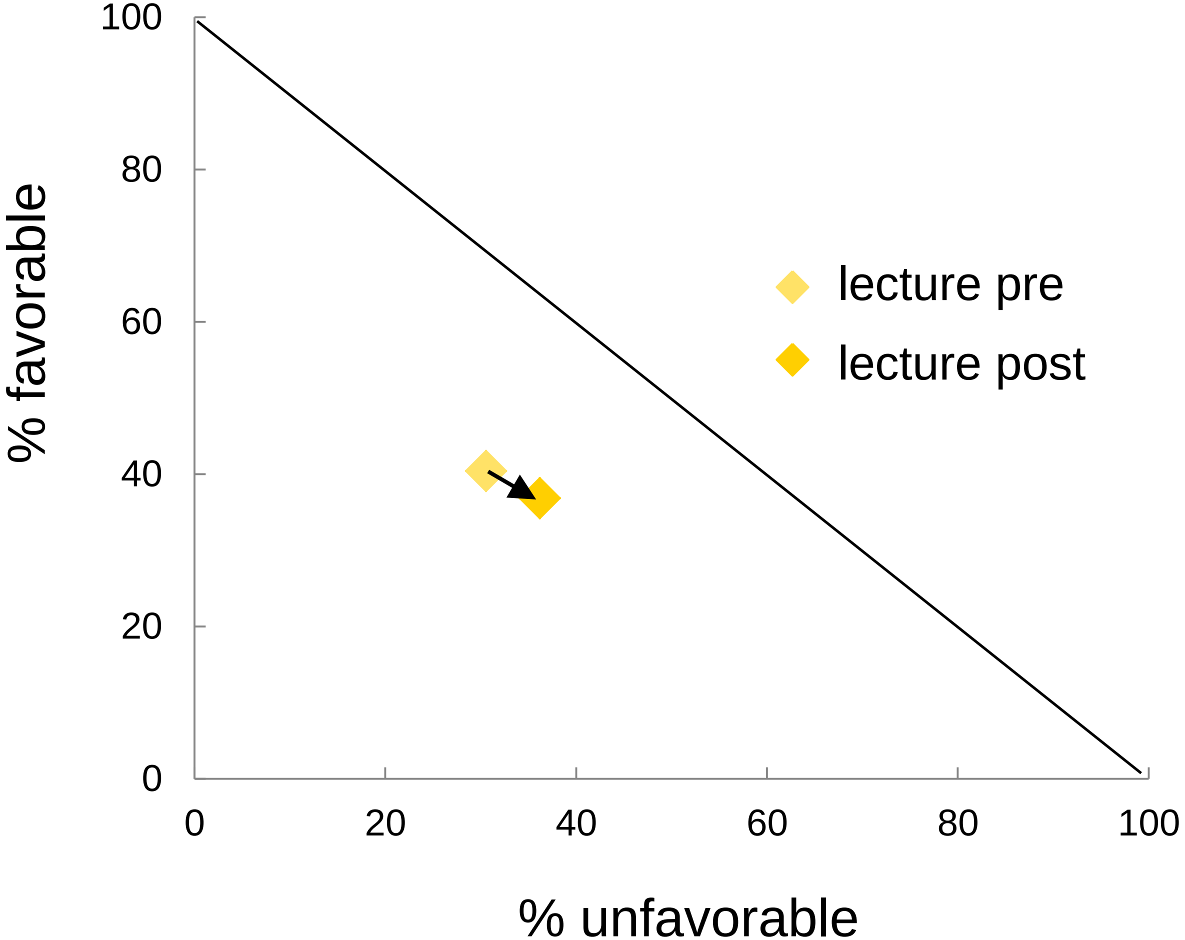

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