Does It Stick? Assessing the Long-Term Impact of IPLS

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IPLS Goals

Help students become prepared and motivated to apply physics in future work

IPLS Design

Organize around “authentic” biomedical applications of physics (*Watkins et al, 2011*)

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Explicitly state value of the physical sciences to these students’ future work (*Expansive framing: Engle et al, 2011)*

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Organize around "authentic" biomedical applications of physics (*Watkins et al, 2011*)

Explicitly state value of the physical sciences to these students' future work (*Expansive framing: Engle et al, 2011)*

Develop physics and quantitative skills using student-centered pedagogy:

- Content knowledge
- Mechanistic reasoning
- Using multiple representations
- Working with quantitative data
- Modeling

IPLS Goals

Help students become prepared and motivated to apply physics in future work

Do they?

No one has answered this (yet)

No one has answered this (yet)
Requires a longitudinal study

Today's talk

- Describe study design, highlighting unique challenges of looking for transfer of IPLS into biology coursework
- Present Year One results
- Describe Year Two new data sources (no analysis yet)

(Pilot) study design

(Pilot) study design

Swarthmore College:

- Small 4-year college, selective admissions
- Close relationships with biology colleagues
- Loyal students

Research questions

- 1. Do IPLS students demonstrate a greater ability to leverage physics competencies in later biology courses, compared to their peers with:
  - no college physics
  - traditional introductory physics?

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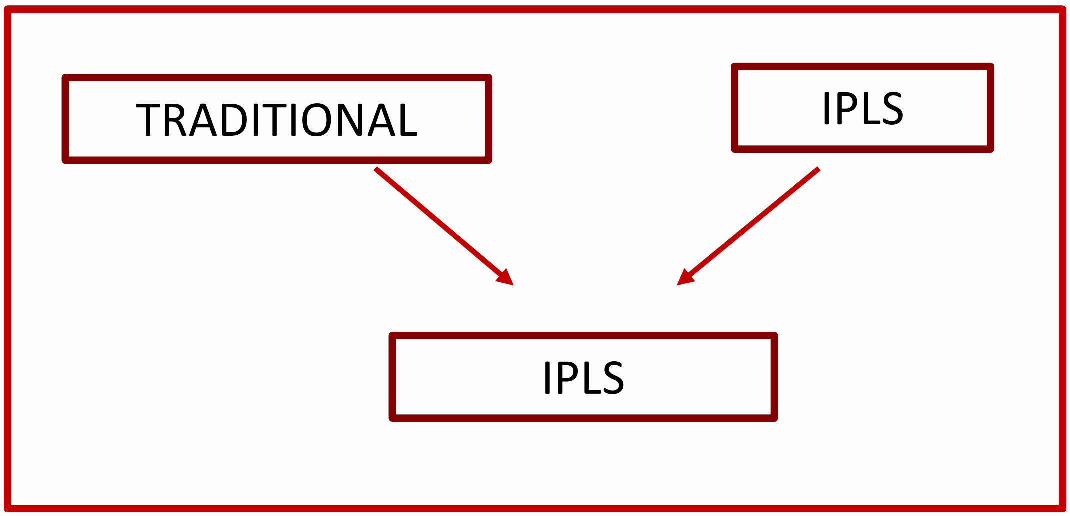
  If so, in what ways?

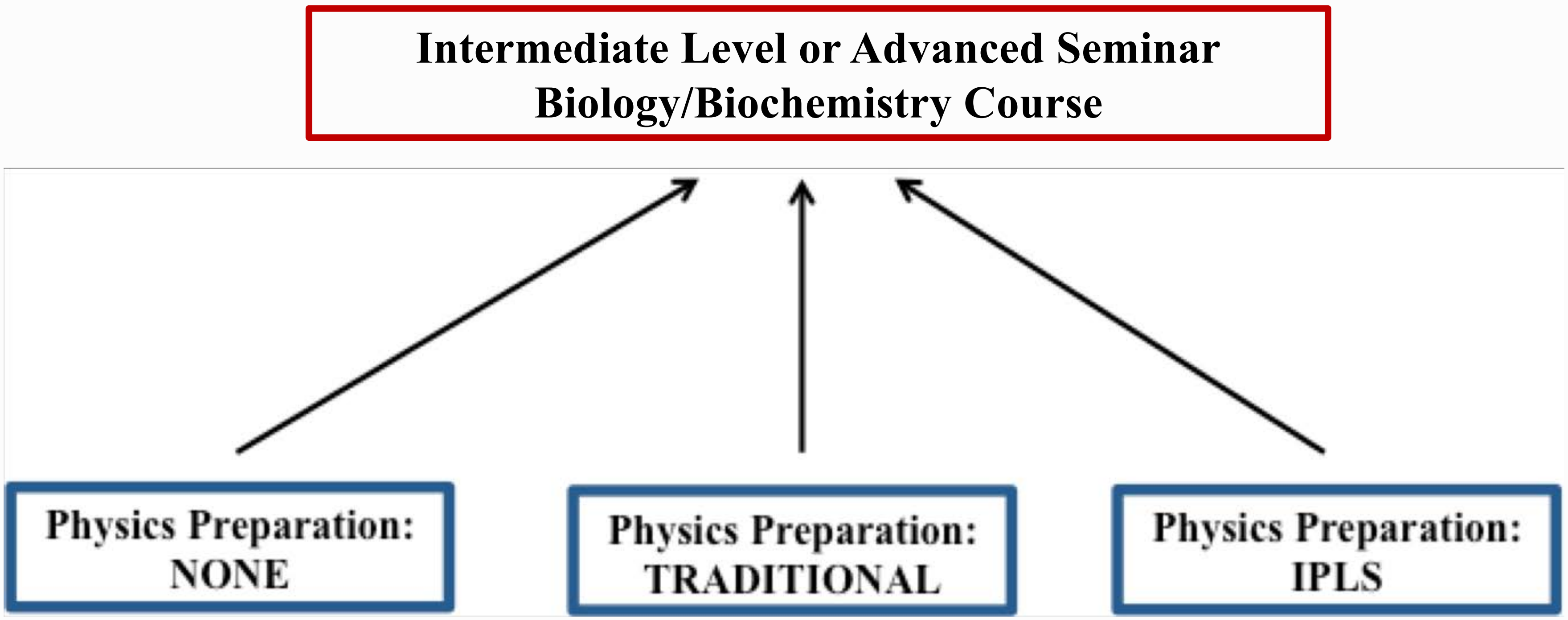
Compare students with different preparation

Semester 1:
(Mechanics)

Semester 2:
(E&M)



IPLS first semester only offered in odd-numbered years


Intermediate Level or Advanced Seminar Biology/Biochemistry Course
Physics Preparation: NONE
Physics Preparation: TRADITIONAL
Physics Preparation: IPLS

Research questions

- 1. Do IPLS students demonstrate a greater ability to leverage physics competencies in later biology courses, compared to their peers with:
  - no college physics (most with HS or AP)
  - traditional introductory physics?

  If so, in what ways?

- 2. Do IPLS students view physics as more relevant and connected to biology and chemistry, compared to their peers?

  If so, in what ways?

Research questions

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  If so, in what ways?

- 2. Do IPLS students view physics as more relevant and connected to biology and chemistry, compared to their peers?

  If so, in what ways?

Our prior work (2018) found IPLS students did, immediately after physics

IPLS supports student interest in physics

Measured post-pre change in student interest in physics with CLASS items:

- Traditional course: all students lose interest
- IPLS: Low initial interest students gain, medium hold steady

Interviewing students and analyzing interest in specific examples:

- Traditional course: students do not recognize connection
- IPLS: students typically find physics relevant and connected to biology

Crouch *et al*, PRPER 2018; Geller *et al*, PRPER 2018

Data sources: Year One

Data gathered from students enrolled in selected intermediate biology courses or intro biochemistry

- Written work on science tasks
- Problem-solving interviews
- Written reflections on relationships between sciences

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Task needs improving

Data sources: Year One

Data gathered from students enrolled in selected intermediate biology courses or intro biochemistry

- Written work on science tasks
- Problem-solving interviews — recruitment issues
- Written reflections on relationships between sciences

Data sources: Year One

Data gathered from students enrolled in selected intermediate biology courses or intro biochemistry

- Written work on science tasks —analysis focus so far
- Problem-solving interviews
- Written reflections on relationships between sciences

Preliminary Year One results

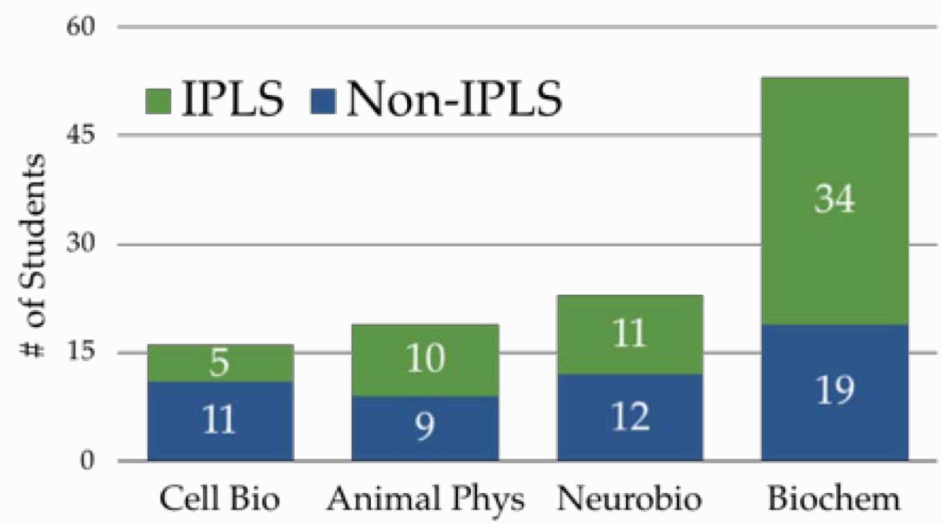
- 1. Do IPLS students demonstrate a greater ability to leverage physics competencies in later biology courses, compared to their peers with:
  - no college physics
  - traditional intro physics

Preliminary Year One results

- 1. Do IPLS students demonstrate a greater ability to leverage physics competencies in later biology courses, compared to their peers with:
  - no college physics — PROBABLY (SMALL N)
  - traditional intro physics — UNCLEAR (VERY SMALL *N*)

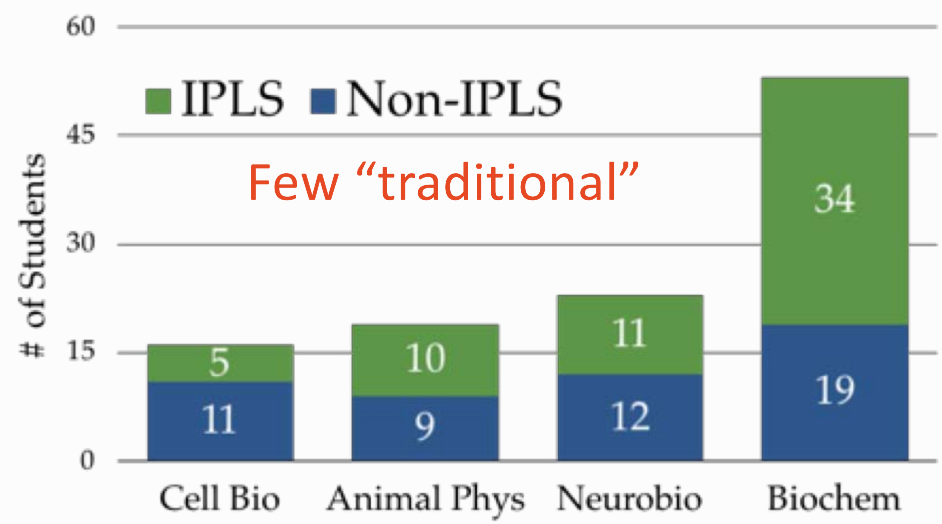
Year One embedded task analysis

- Cell Biology (S2017, *N* = 16)
- Animal Physiology (F2017, *N* = 24)
- Neurobiology (S2018, *N* = 23)
- Biochemistry (S2018, *N* = 53)



Year One embedded task analysis

- Cell Biology (S2017, *N* = 16)
- Animal Physiology (F2017, *N* = 24)
- Neurobiology (S2018, *N* = 23)
- Biohemistry (S2018, *N* = 53)



Methodological questions

- How much input should the IPLS instructors/research team have in designing the embedded tasks?

Input into embedded task design

LESS INPUT — **MORE INPUT**

- Less likely to elicit physical reasoning
- More convincing evidence of transfer

- More likely to elicit physical reasoning
- Less convincing evidence of transfer

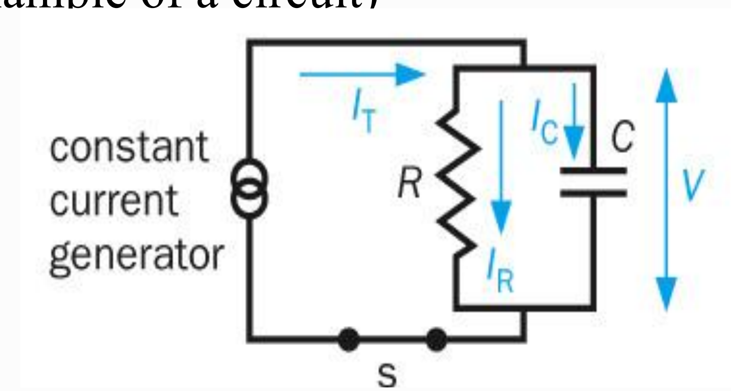
YEAR 1
EMBEDDED TASKS

Examples of tasks

(30 pts) **Skeletal muscle function**

A mutation in one of the "ruler" proteins in skeletal muscle causes the thick filaments to be longer than usual….**What will be the effect of this mutation on the length-tension curve for the sarcomere?**

Based on the data shown in Figure 5i [referencing a paper that accompanied the task], draw a circuit model assuming only the 2 receptor types. (See below for an example of a circuit)



Methodological questions

- How much input should the IPLS instructors/research team have in designing the embedded tasks in biology courses?
- How do we distinguish what is learned in the biology course from what was gained from IPLS?
(Physics is not a prerequisite for the biology course)

Looking for evidence of “using physics”

- Capitalize on unprompted physical reasoning or methods
- Check that correctness is independent of “using physics”

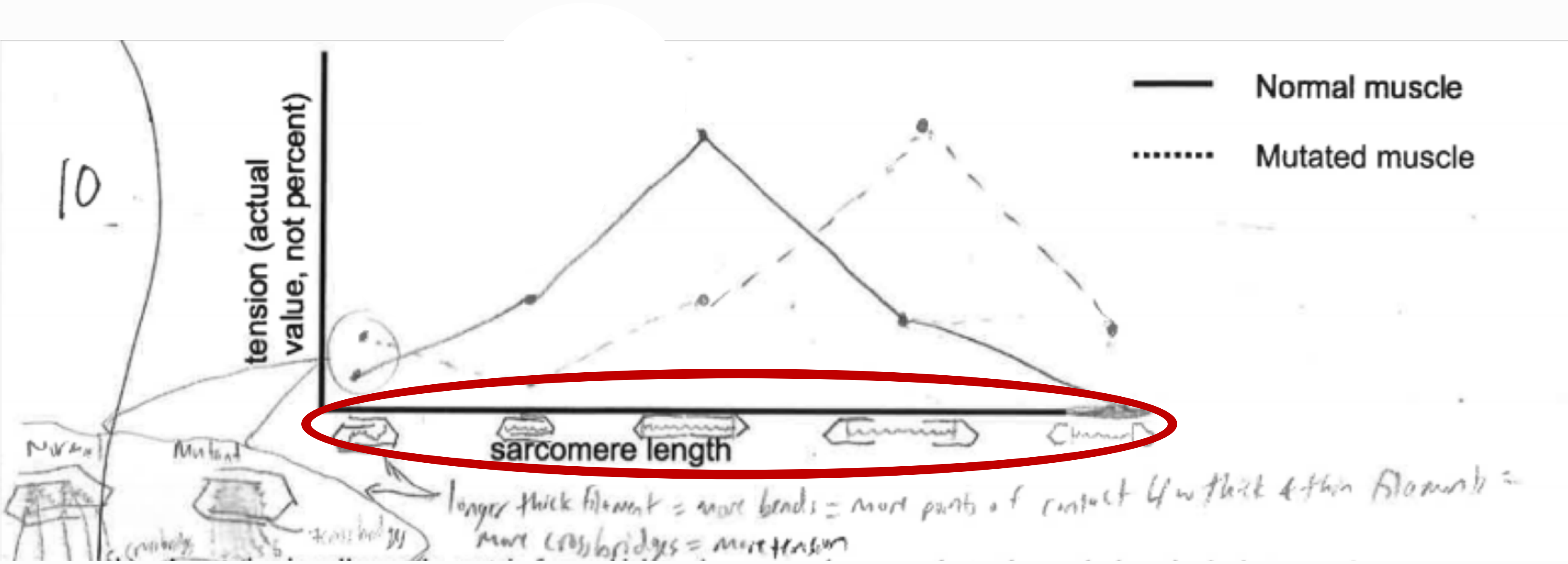
Looking for evidence of "using physics"

- Capitalize on unprompted physical reasoning or methods
- Check that correctness is independent of "using physics"

1. Developed emergent coding scheme for physical reasoning/skills in each task

[from Skeletal Muscle Function Problem in Animal Physiology]

What will be the effect of a specific mutation on the length-tension curve for a sarcomere?



This student's work includes detailed diagrams (unprompted) that reveal their underlying mechanistic thinking.

Looking for evidence of “using physics”

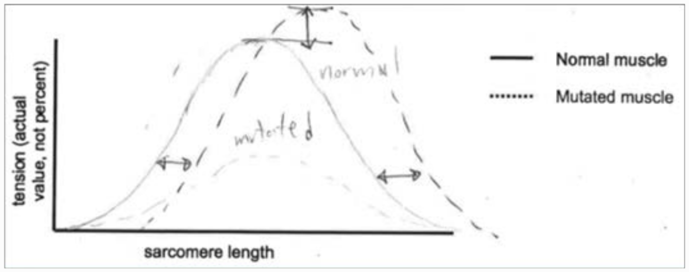
- Capitalize on unprompted physical reasoning or methods
- Check correctness is independent of “using physics”

1. Developed emergent coding scheme for physical reasoning/skills in each task

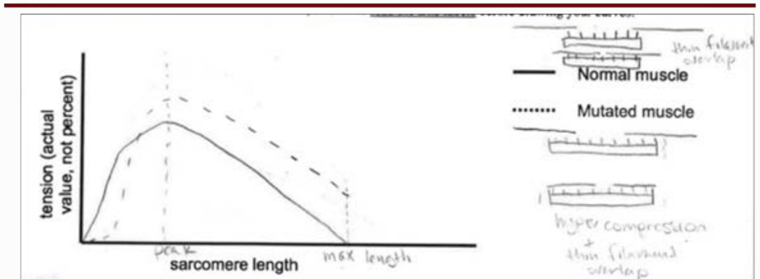
Each instance of physical reasoning gets 1 point

Example student responses

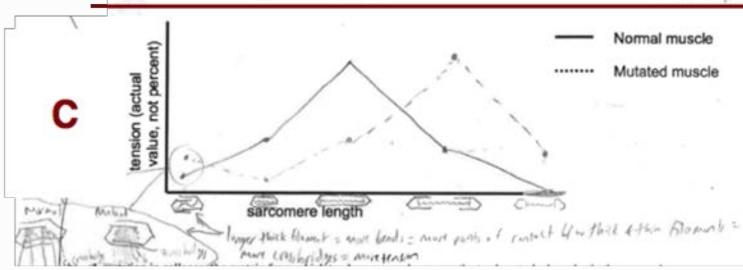
A



B



C



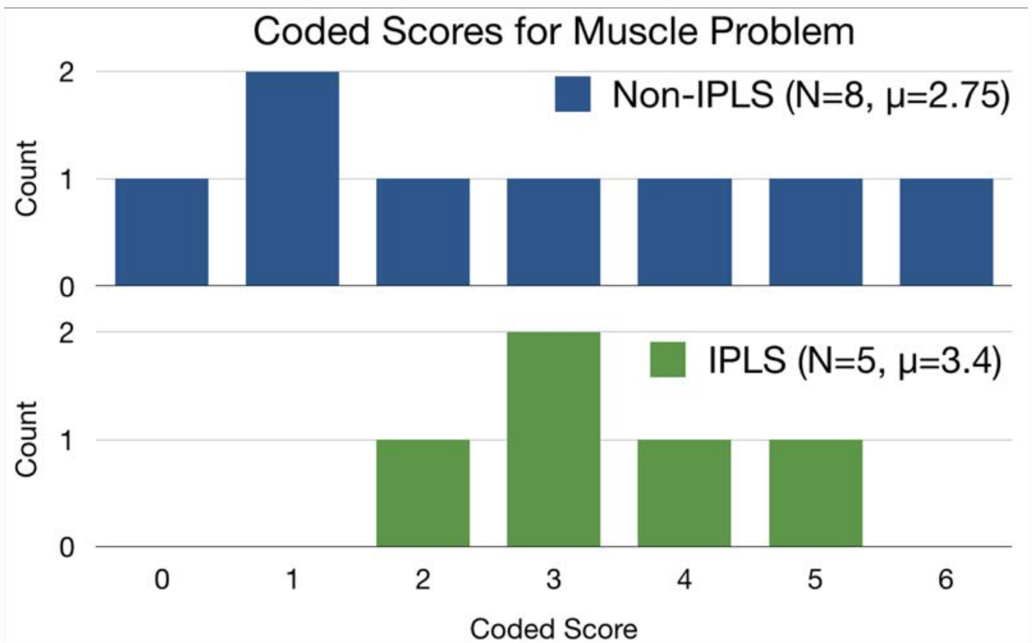
Codes

- Description of changing parameters
- Diagram of muscle in different configurations
- Graph accounts for buckling
- Graph labeled

CODE

STUDENT	Description	Diagram	Buckling	Label
A (None)	✘	✘	✘	✘
B (Trad.)	✘	✔	✔	✔
C (IPLS)	✔	✔	✔	✔

Single Task Scores (Animal Phys)



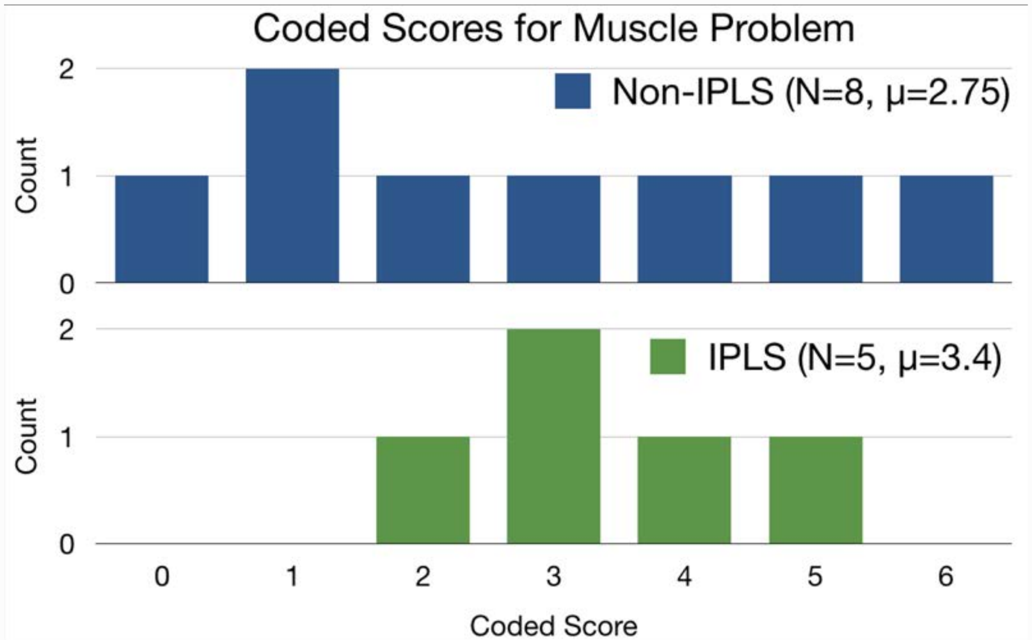
$p = 0.50; \Delta\mu = +0.65$

p-values were determined with a rank-sum test (also called a Mann-Whitney *U* test or Wilcoxon test), suitable for non-parametric data and small *N*.

Non-IPLS:

- > 75% no Swarthmore physics
- < 25% traditional physics at Swarthmore

Single Task Scores (Animal Phys)

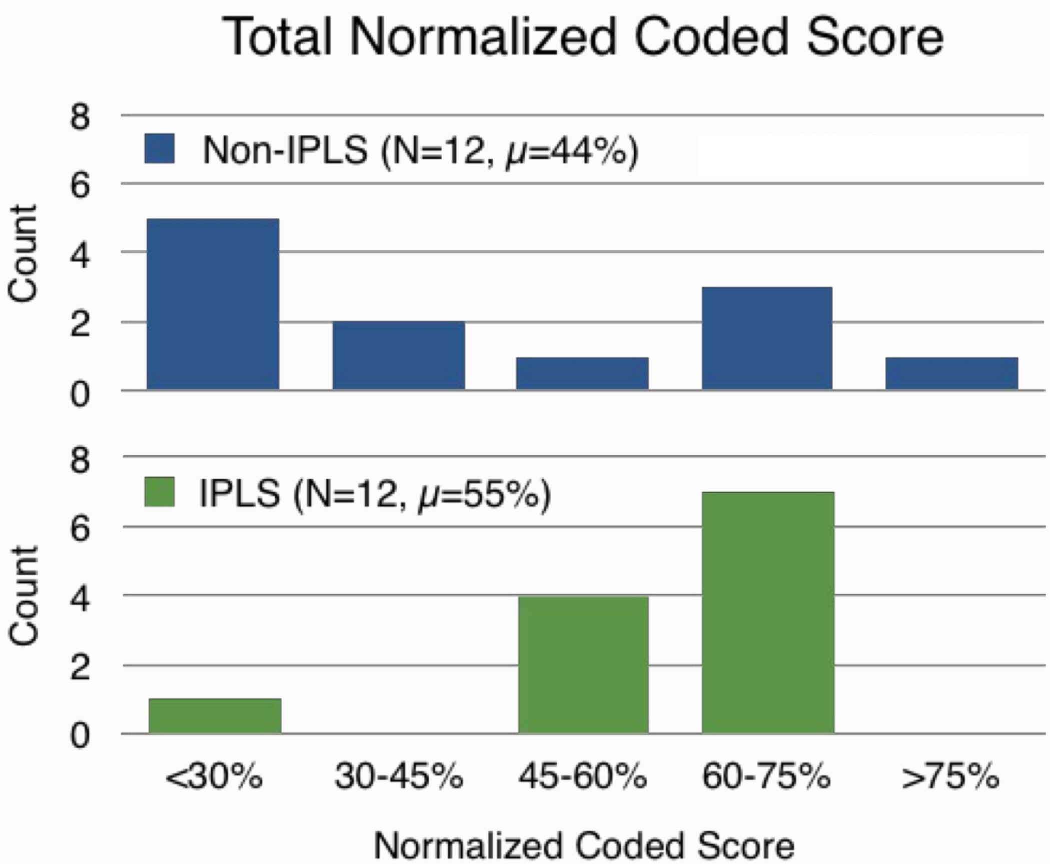


$p = 0.50; \Delta\mu = +0.65$

For each individual task,

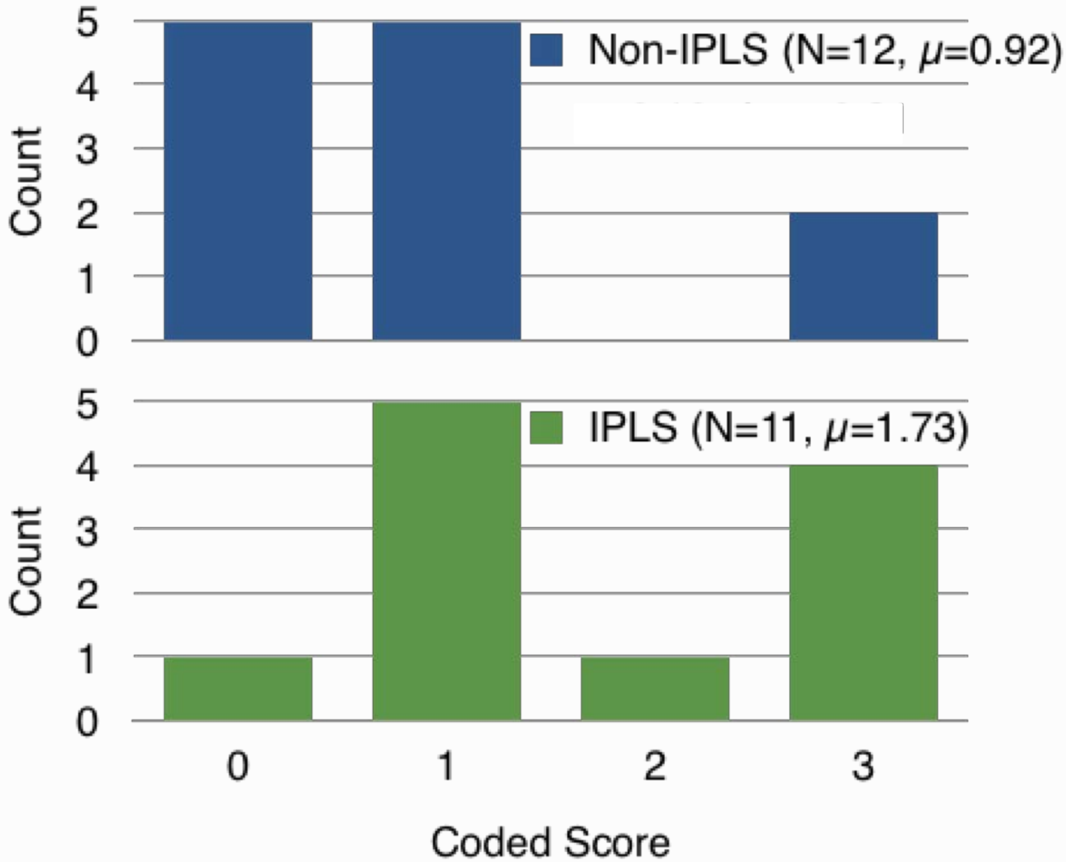
$$\mu_{IPLS} \geq \mu_{non-IPLS}$$

All tasks combined (Animal Phys)



$p = 0.31; \Delta\mu = 11\%$

Single Task Scores (from Neurobiology)



$p = 0.10; \Delta\mu = +0.81$

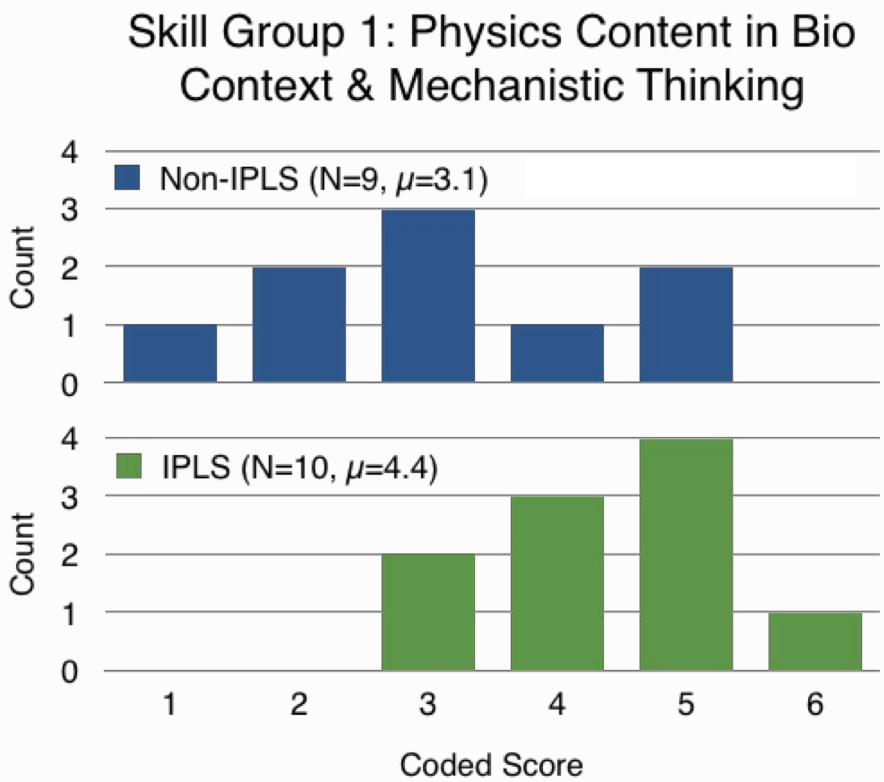
Looking for evidence of "using physics"

- Must disentangle what is gained from IPLS vs. the biology course
- Capitalize on unprompted physical reasoning or methods
- Correctness is independent of "using physics"

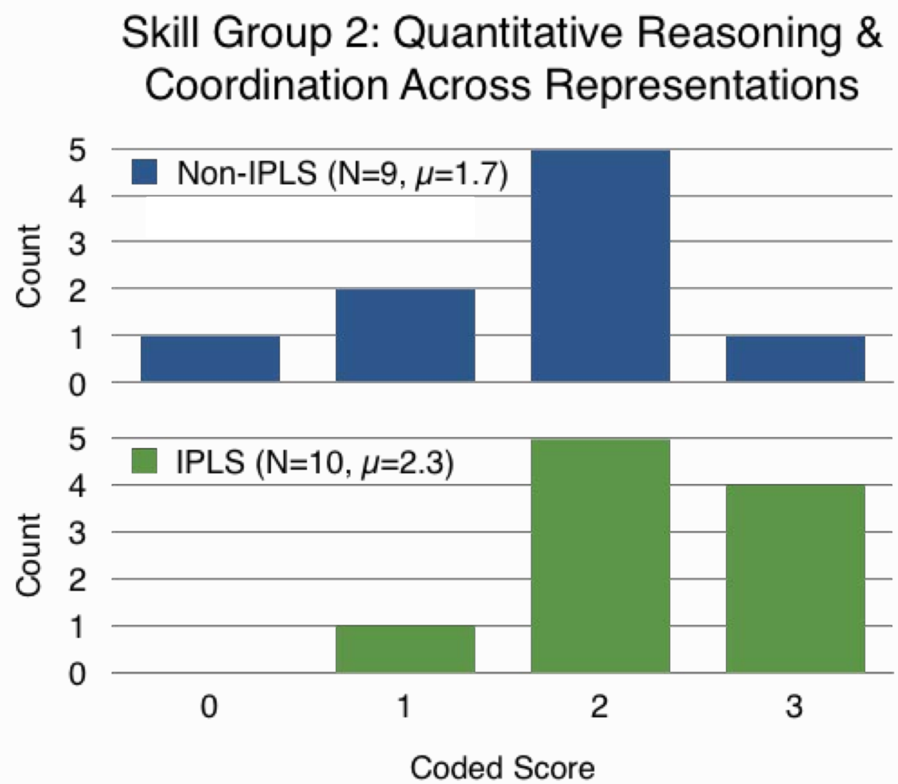
1. Developed emergent coding scheme for physical reasoning/methods in each task

2. Categorized codes according to intended IPLS competencies:
   - Physical concepts applied to a biological system
   - Mechanistic reasoning
   - Coordinating multiple representations
   - Quantitative reasoning

Codes grouped by skill



$p = 0.04; \Delta\mu = 1.3$



$p = 0.12; \Delta\mu = 0.6$

Year One embedded task summary

- For every task analyzed, $\mu_{IPLS} \geq \mu_{non-IPLS}$!
- Results strongly suggest correlation between IPLS and physical reasoning
- Larger sample size needed!

Year Two: What changes are needed?

Embedded tasks:

- Bigger sample size
- More “traditional” students

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Embedded tasks:

- Bigger sample size
- More “traditional” students

Attitudes:

- Better written tasks
- Survey data

Think-aloud interviews: Better recruitment

Year Two changes

Embedded tasks:

- Sample size
- More “traditional” students

Attitudes:

- Written tasks
- Survey data

Think-aloud interviews: Instructor gave extra credit (*N* = 21)

New data sources: Year Two

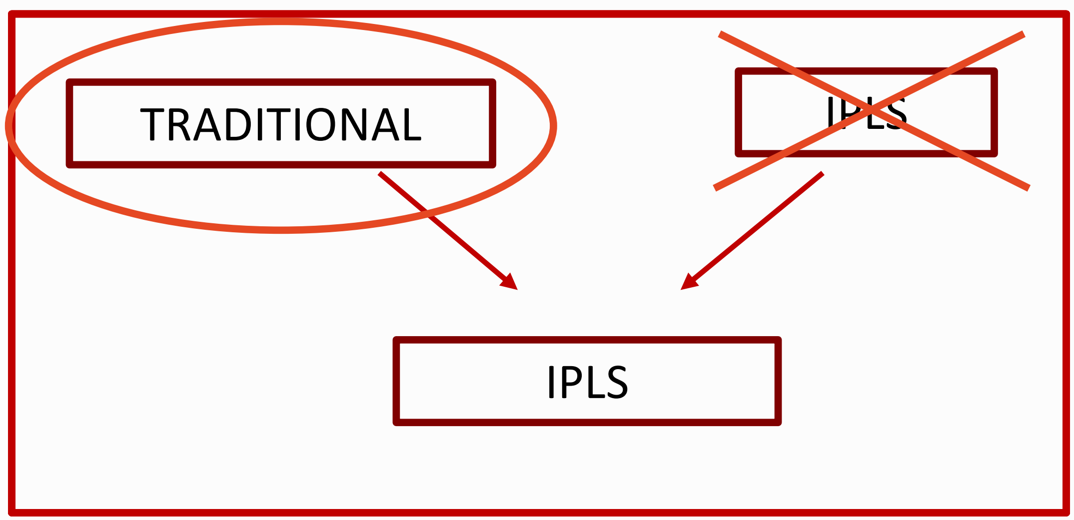
Data gathered from students enrolled in selected intermediate biology courses or intro biochemistry

- Written work on science tasks
- Problem-solving interviews
- Written reflections on relationships between sciences
- Interdisciplinary connections survey (NEXUS)

Year Two opportunity

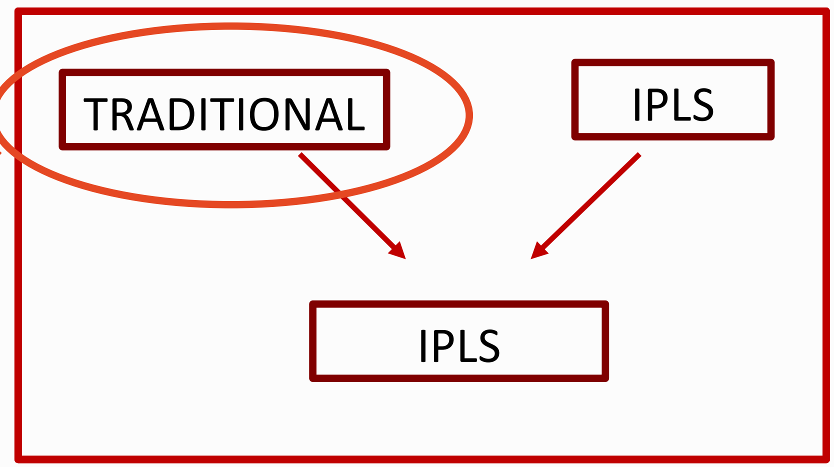
Semester 1:
(Mechanics)

Semester 2:
(E&M)



Only TRADITIONAL Semester 1 offered!

Year Two opportunity



Traditional first semester course:

- covered nearly all the same physics topics as IPLS
- included biological applications (peripherally)
- Implicitly, rather than explicitly, discussed modeling process
- did not frame course as preparing students for future use of physics

New data sources: Year Two

Data gathered from students enrolled in selected intermediate biology courses or intro biochemistry

- Written work on science tasks
- Problem-solving interviews
- Written reflections on relationships between sciences
- Interdisciplinary connections survey (NEXUS)

Data also gathered from students completing intro physics

- Written transfer task
- Attitude surveys and interviews

SWARTHMORE

Transfer task design

- End of semester task modeling an unfamiliar biological situation: fluid dynamics of sap pressure in trees
- Give identical task to traditional and (next year) IPLS

Transfer task: part (a)

Adult male giraffes reach a height of roughly 6 m. The minimum pressure of the blood leaving the giraffe's heart is 1.24 atmospheres (124 kPa). Find an approximate value for the minimum blood pressure in the giraffe's brain when its neck is extended to its full height. You may infer information from the picture provided.

Please briefly explain your reasoning, including how you decided which equations to use, and any approximations you made.

Transfer task: part (a)

Adult male giraffes reach a height of roughly 6 m. The minimum pressure of the blood leaving the giraffe's heart is 1.24 atmospheres (124 kPa). Find an approximate value for the minimum blood pressure in the giraffe's brain when its neck is extended to its full height. You may infer information from the picture provided.

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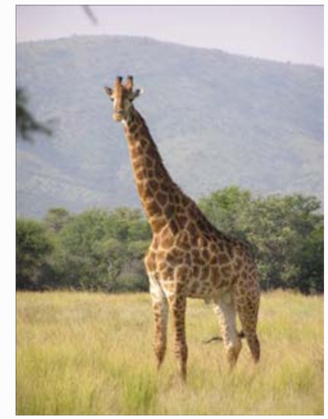

Adult male giraffes reach a height of roughly 6 m. The minimum pressure of the blood leaving the giraffe's heart is 1.24 atmospheres (124 kPa). Find an approximate value for the minimum blood pressure in the giraffe's brain when its neck is exten … nfer information f …

Purpose: to prime students to think about role of gravity in fluid pressure

Please briefl … ling how you decided which equations to use, and any approximations you made.

Transfer task (part b)

In trees, water is carried from the roots to the leaves by the flow of sap through stiff tube-like structures, called xylem. A typical xylem diameter is 100 µm. In the main trunk of the tree, they extend close to the full height of the tree, which is commonly as great as 30 meters tall. These extremely narrow, long tubes contain a continuous column of water which can then flow into the leaves. Evaporation of water from the leaves (called transpiration) causes water to be steadily drawn up. The leaf structure allows the pressure of water in the xylem to not necessarily be the same as atmospheric pressure.

Transfer task (part b)

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the tree, whi … neters tall.
These extrem … a continuous
column of wa … e leaves.
Evaporation …
transpiration) causes water to be steadily drawn up. The leaf structure allows the pressure of water in the xylem to not necessarily be the same as atmospheric pressure.

- **Give dimensions of “stiff tube-like” vessels (xylem) through which sap flows**
- **Pressure at top doesn’t have to be atmosphere**

Transfer task (part b, cont'd)

Consider a tree in which sap flows through each 100 μm-diameter xylem at a volume flow rate of $1.1\text{x}10^{-10}$ m^3/s (equal to $1.1\text{x}10^{-4}$ mL/s or 0.40 mL/hr), corresponding to an average flow speed of 0.014 m/s. If the pressure in the roots is equal to atmospheric pressure, what is the pressure at the top of a 30 m tall xylem in the trunk?

Please briefly explain the reasoning you used to find your answer, including how you decided which equations to use, as well any approximations you made.

Transfer task

Consider a tree in which sap flows through each 100 μm-
diamet … ^{10} m^3/s
(equal … nding to
an ave … ure in the
roots i … ne
pressure at the top of a 30 m tall xylem in the trunk?

Students must Identify and justify choice of model (viscous/nonviscous) from physical situation described in problem

Please briefly explain the reasoning you used to find your answer, ***including how you decided which equations to use, as well any approximations you made.***

Transfer task

Physical clue to use viscous model (dimensions also provided)

In trees, water is c
the flow of sap th
xylem. A typical xy
trunk of the tree, they extend close to the full height of the tree, which is commonly as great as 30 meters tall. These extremely narrow, long tubes contain a continuous column of water which can then flow into the leaves. Evaporation of water from the leaves (called transpiration) causes water to be steadily drawn up. The leaf structure allows the pressure of water in the xylem to not necessarily be the same as atmospheric pressure.

Transfer task

Viscosity of water mentioned in earlier task instructions (not in problem itself)

The last page gives equations and values of useful parameters such as the density and viscosity of water.

Transfer task

The last page gives equations and values of useful parameters such as the density and viscosity of water.

Equation list gives nonviscous flow equation (Bernoulli) and viscous flow through horizontal cylindrical pipe (Hagen-Poiseuille).

For fully correct analysis, students must *combine* effects of gravity and viscosity.

Transfer task (part c)

You should have found different signs for your answers to (a) and (b). In this course, we have not discussed the possibility of negative values of pressure. A more in-depth study of pressure reveals that negative pressures can exist … Just as for posit… …oss a surface …

Very minimal new material to probe ability to learn (quasi-PFL)

Transfer task (part c, cont'd)

A critical difference between the fluid transport systems of trees and animals like giraffes is that blood vessels through which blood flows are made of a stretchy material, while the xylem through which sap flows are made of a very rigid material.

How do your results for (a) and (b) illustrate part of the reason why trees can grow much taller than land animals? ***Explain your answer using the ideas from this course and your physical intuition. Be as specific as you can be in your explanation.***

Transfer task (part c, cont'd)

A critical difference between the fluid transport systems of trees essels through hy materia ws are made o

Can students apply what they already know about pressure differences with intuition about rigid vs flexible materials?

How do your results for (a) and (b) illustrate part of the reason why trees can grow much taller than land animals? ***Explain your answer using the ideas from this course and your physical intuition. Be as specific as you can be in your explanation.***

Think-aloud interviews

Think-aloud interview task design

LESS INPUT | **MORE INPUT**

THINK-ALOUD INTERVIEW PROMPTS

LESS INPUT

- Less likely to elicit physical reasoning
- More convincing evidence of transfer

MORE INPUT

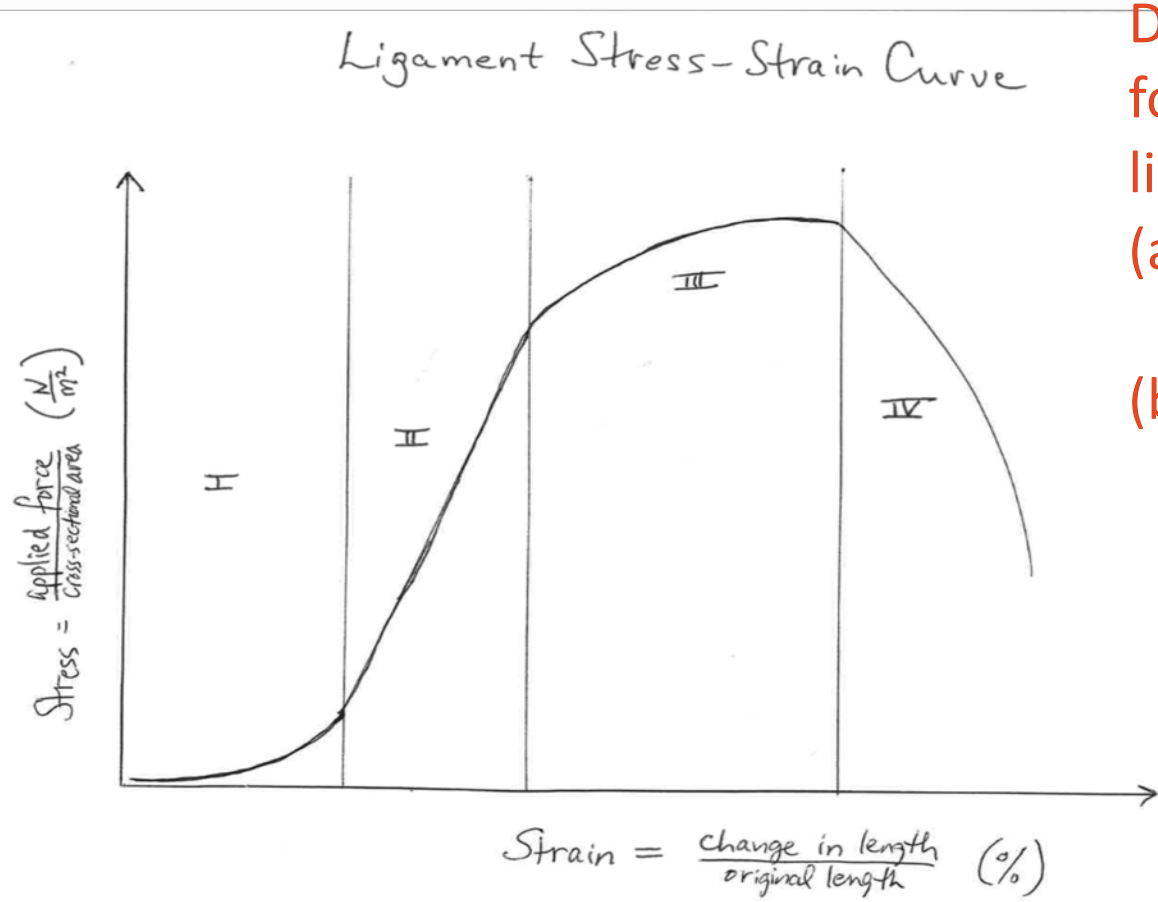
- More likely to elicit physical reasoning
- Less convincing evidence of transfer

Think-aloud interviews

Describe an to measure the force-extension curve for a ligament

(a) Students construct a graph from a description

Think-aloud interviews



Describe an to measure the force-extension curve for a ligament

(a) Students construct a graph from a description
(b) Students interpret data provided by interviewer

Think-aloud interviews: challenges

- Context primes them for detailed biological thinking
  - Recruited students from the course
  - Interview scheduled one week before final exam
- How much does the interviewer prompt students toward physical reasoning?

Pilot year of a pilot study…

- Promising results from embedded task analysis
- Anticipate challenges with interpreting think-aloud interviews
- New data sources added
- Any and all feedback is welcome!

Thank you!

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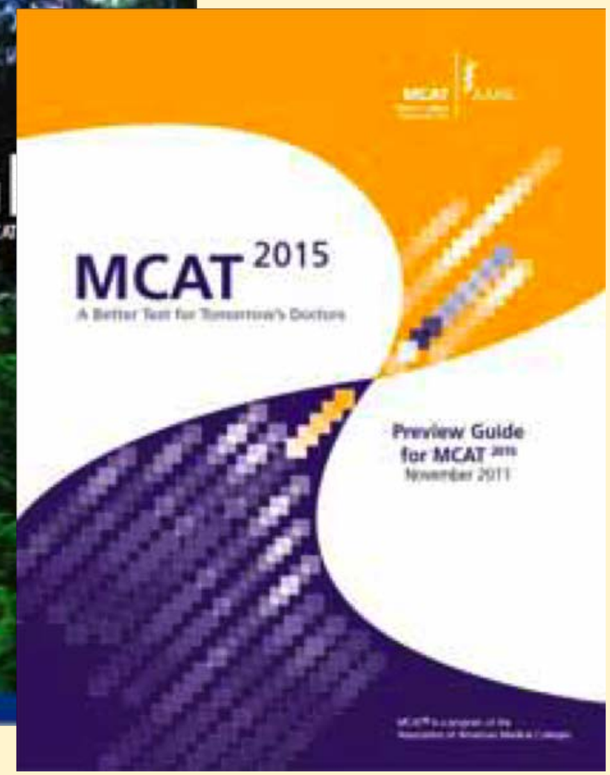
Calls for reform

2003

2009

2011

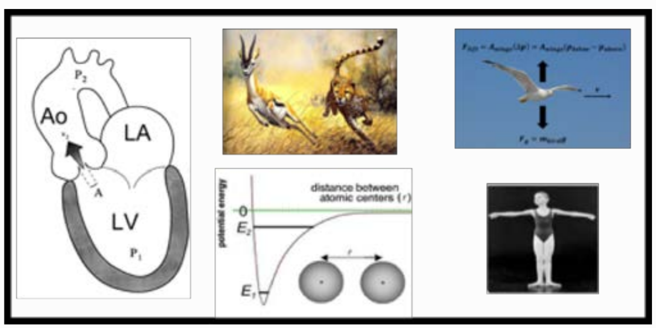


2013

IPLS course design: Content

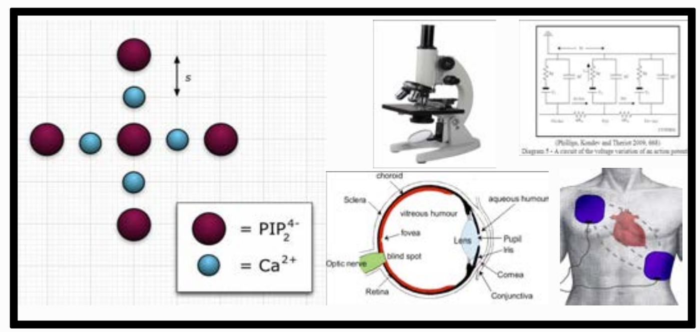
IPLS Mechanics

- Kinematics and Dynamics: ***random vs. coherent motion, biomechanical stability***
- Energy: ***chemical energy***
- Fluids: ***cardiology and flight***
- Thermodynamics: ***heat conduction and free energy***

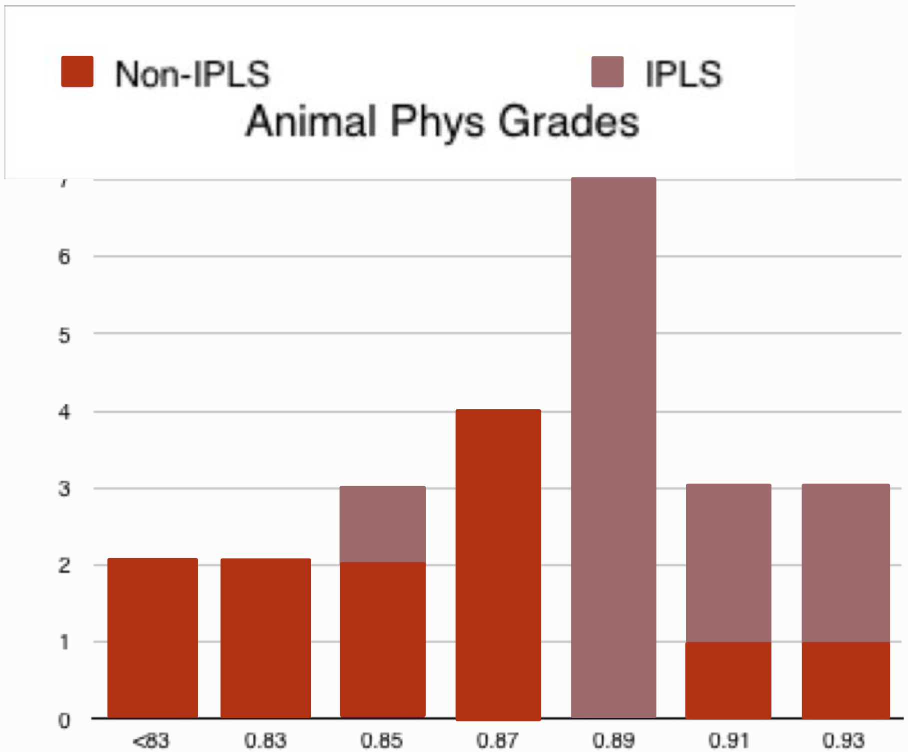


IPLS E&M

- Electricity/circuits: ***cell membrane, nerve signaling***
- Magnetism and induction: ***magnetic sensing, NMR***
- Optics: ***animal vision and microscopy***
- Waves: ***echolocation***



Grades: The IPLS student group earned higher Animal Physiology grades than did Non-IPLS student group

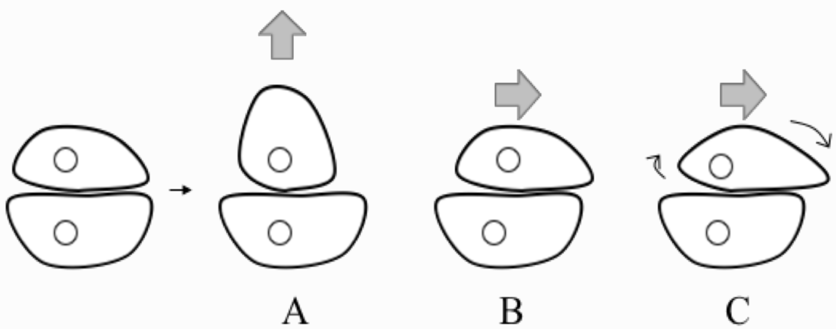


$p = 0.04; \Delta\mu = 4\%$

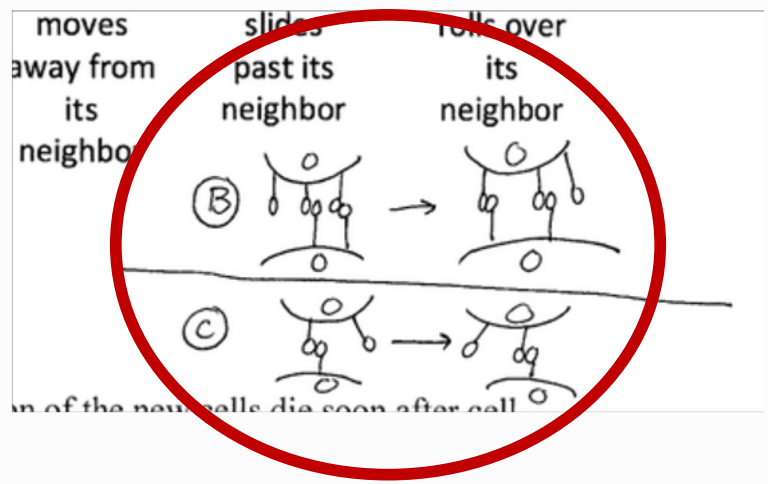
- The IPLS student grade distribution in our sample matches that of all IPLS students.
- The IPLS students also do not seem to be "better biology students," as measured by intro Bio grades.
  - No correlation exists between IPLS *grades* and Animal Physiology grades.
    - No such correlation exists with Neurobiology grades

[from Cell Adhesion Problem in Cell Biology]

How would you model this mechanical resistance? Rank from greatest to least resistance.



Cell adhesion



This student's work includes multiple detailed diagrams (unprompted) that account for individual cadherin-cadherin interactions.

[from Hamster Problem in Animal Physiology]

Write the equation for heat exchange by conduction and define each of the 6 terms in the eqn.

$$\dot{H} = \frac{K A (T_2 - T_1)}{d}$$

$\dot{H}$ = rate of Heat exchange

K = conductivity coefficient [measure of a substances ability to conduct heat]

A = Surface area of contact between two objects/thermal zones

d = thickness of boundary between thermal zones

T_2 = Temperature of thermal zone 2

T_1 = Temperature of thermal zone 1

Two different student responses

A

$$\dot{H} = \frac{kA(T_2 - T_1)}{d}$$

$\dot{H}$ = rate of ~~Heat~~ exchange
K = Conductivity coefficient [measure of a substances ability to conduct heat]
A = Surface area of contact between two objects/ thermal zones
d = thickness of boundary between thermal zones
T_2 = Temperature of thermal zone 2
T_1 = Temperature of thermal zone 1

B

$$\dot{H} = \frac{kA(T_2 - T_1)}{d}$$

$\dot{H}$ = rate of heat exchange w/ envi. $\propto$ metabolic rate
k = conductivity: a constant property of the material surrounding
A = surface area of animal
T_2 = outside T T_1 = T_b (or the 2 diff Ts between
d = thickness of barrier btwn T_1 and T_2

Codes

- Understands heat exchange as rate
- Applies equation
- Includes diagram
- Defines conductivity 'k'

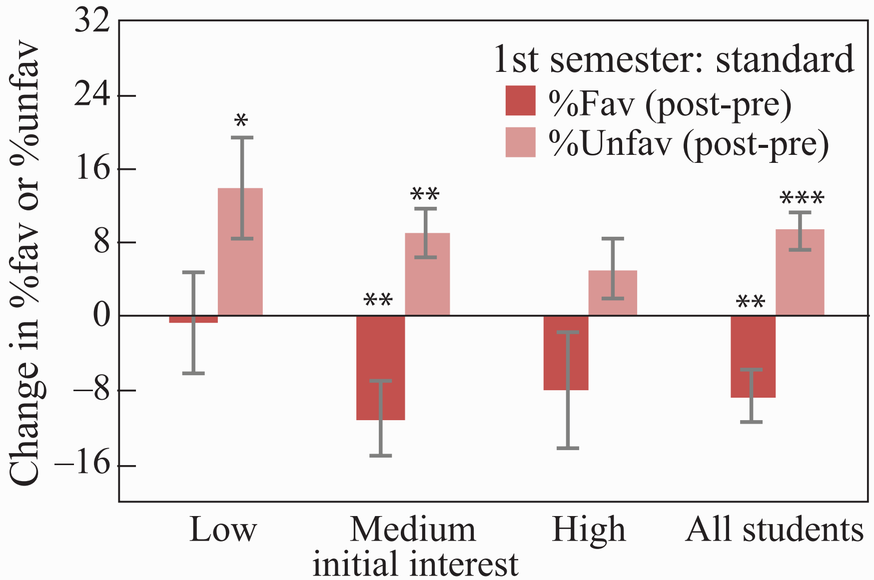
CODE

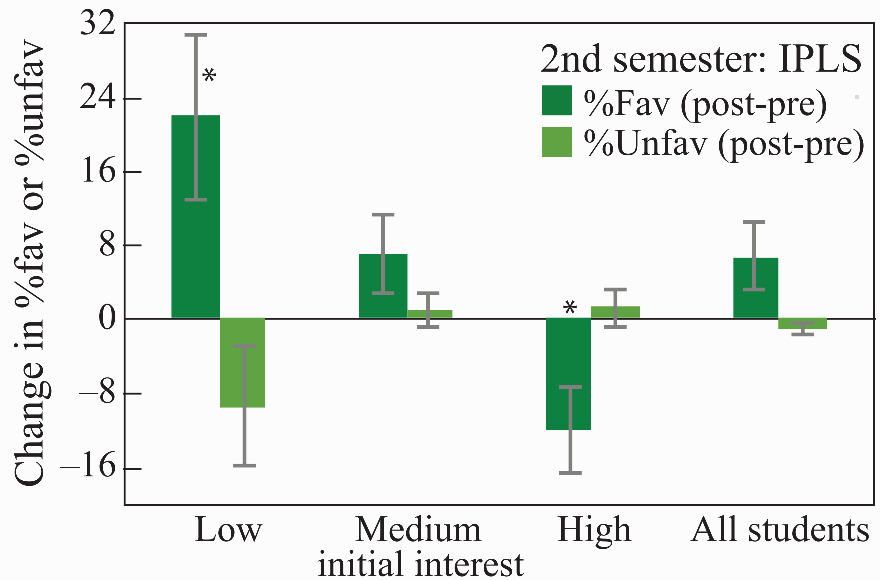
STUDENT

	Rate	Application	Diagram	defines 'k'
Y (None)	✗	✗	✗	✓
Z (IPLS)	✓	✓	✓	✓

IPLS supports student interest in physics

Pre-post change in student interest in physics measured with CLASS items

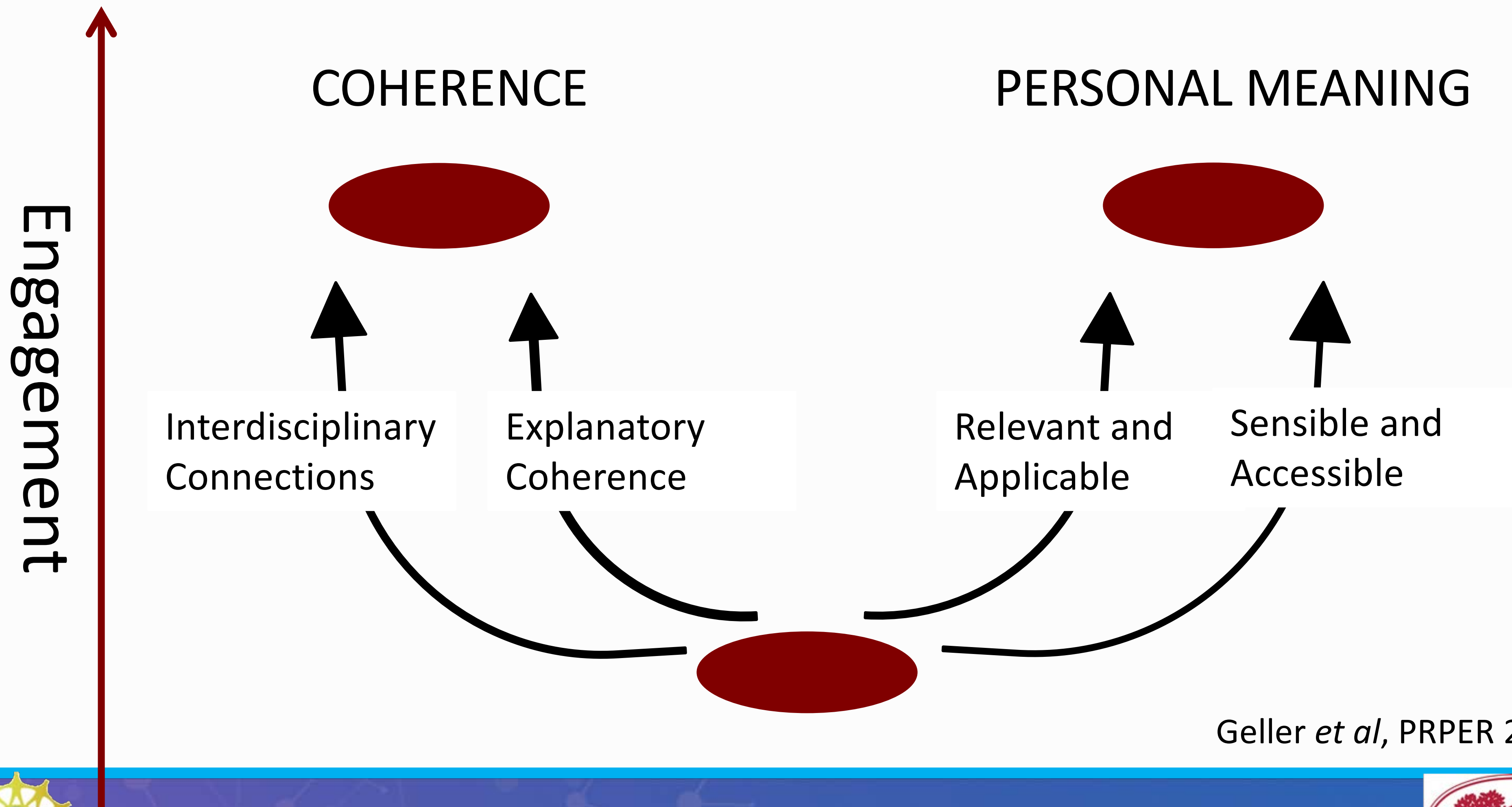




- All lose interest in physics in standard course
- Low & medium initial interest hold steady or gain in IPLS

Crouch *et al*, PRPER 2018

IPLS students typically find physics relevant and connected to biology



Geller *et al*, PRPER 2018