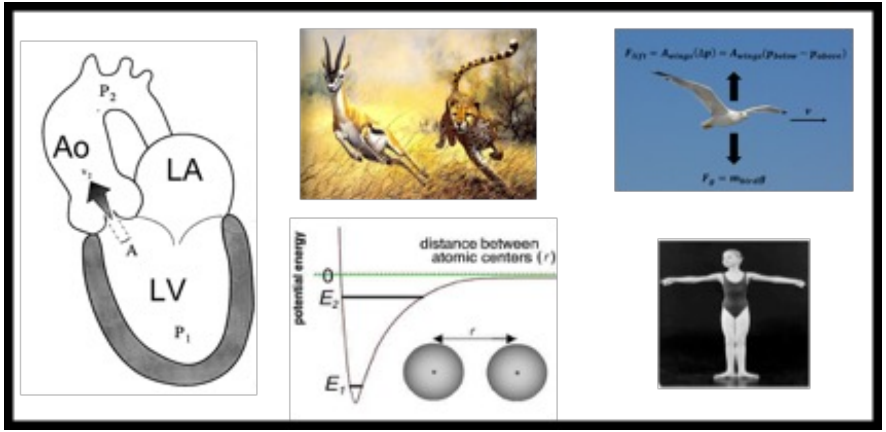
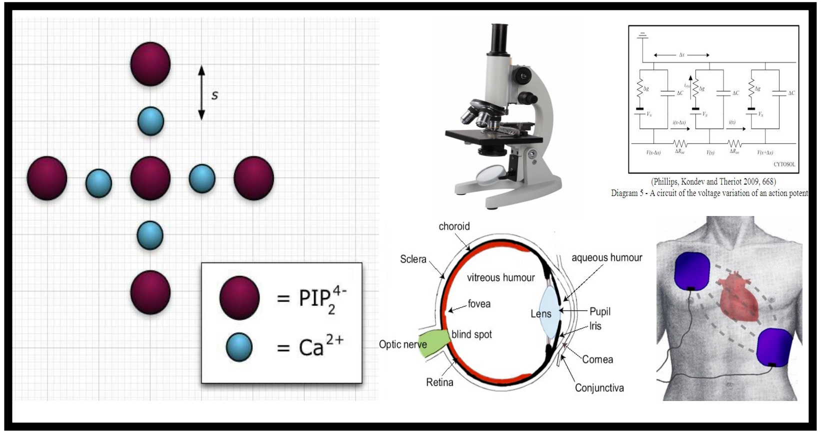
Does it stick? A longitudinal study of introductory physics for life sciences at a small college





Ben Geller and Catherine Crouch

Swarthmore College

Physics Education Research Conference

July 11, 2024

An interdisciplinary team effort!


Sara Hiebert Burch (Biology)

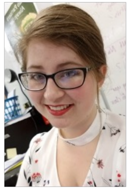

Ann Renninger (Swarthmore Ed.)


Chandra Turpen


Stephen Hackler (Swarthmore Physics)


Jack Rubien ’20


Jonathan Solomon ’20


Haley Gerardi ’17


Aqil MacMood ’20


Nikhil Tignor ’24


Rain White’24


Brandon Daniel-Morales ’24

NSF 1710875

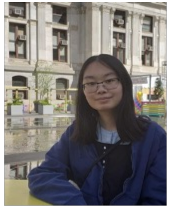
NSF 2142074


Maya Tipton ’23


Gwendolyn Rak ’22


Nathaniel Peters ’18


Panchompoo Wisittanawat ’13


Angelina Tjia ‘26


Drake Roth ‘25


Lundy Zheng ‘26

SWARTHMORE

Swarthmore College

- Small, highly *selective* and highly *diverse* liberal arts college (nearly 30% first-gen)
- ~1650 students total, *all undergraduates*
- Emphasis on creating meaningful *research opportunities* for students, and on *interdisciplinary learning*

IPLS students at Swarthmore:
- mostly pre-med or life science majors
- mostly (~80%) sophomores and juniors
- no formal bio/chem prereqs, but most have taken courses in both areas.

SWARTHMORE

Longitudinal study (and prior work): Papers provided on our website

Today’s talk

1. What is IPLS* and what are we trying to learn about it?
2. Interest and relevance
3. Do skills endure?

*IPLS = Introductory Physics for Life Sciences

Today’s talk

1. **What is IPLS* and what are we trying to learn about it?**
2. Interest and relevance
3. Do skills endure?

*__IPLS__ = __I__ntroductory __P__hysics for __L__ife __S__ciences

BIO 2010, NRC (2003)
Scientific Foundations for Future Physicians (2009), HHMI/AAMC
Vision & Change, AAAS (2011)
MCAT^{2015} (2013)

A (the?) central goal of IPLS*:

Make physics evidently valuable and meaningful for life science students, i.e., to ***make it relevant***

* "**I**ntroductory **P**hysics for the **L**ife **S**ciences"

To achieve this relevance requires knowing our students.*

*Relevance: *the quality or state of being closely connected or appropriate*

*Relevance pertains to both **content** and **skills**…*

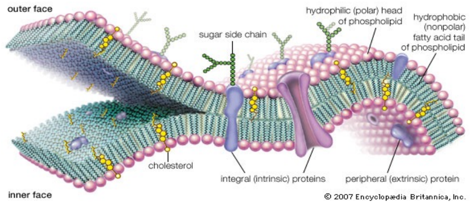
*… and we hope students develop positive **attitudes** about the relevance of physics*

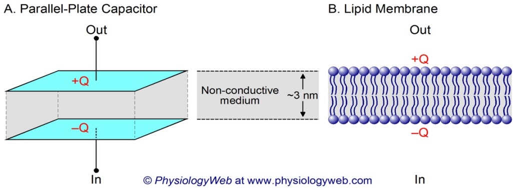
All the calls from professional society reports I showed
Meredith & Redish, *Physics Today* (2013)
Redish et al., *AJP* (2014)

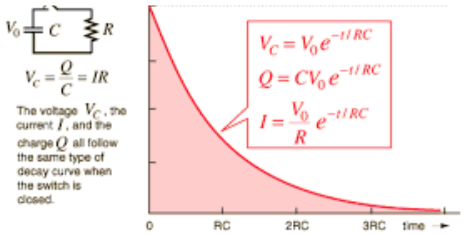
Crouch et al., *PR-PER* (2018)
Geller et al., *PR-PER* (2018)
Nair and Swatelle, *PR-PER* (2019)

Foster relevant scientific skills

Coordinating across representations







BIOLOGICAL SYSTEM
(Cell Membrane)

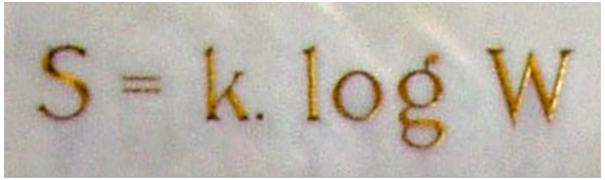
↕

SIMPLE PHYSICAL MODEL
(Electric Capacitor)

↕

GRAPHS & EQUATIONS
(associated with charging/discharging a capacitor)

Making IPLS relevant is not easy…



$$\Delta G = \Delta H - T\Delta S$$

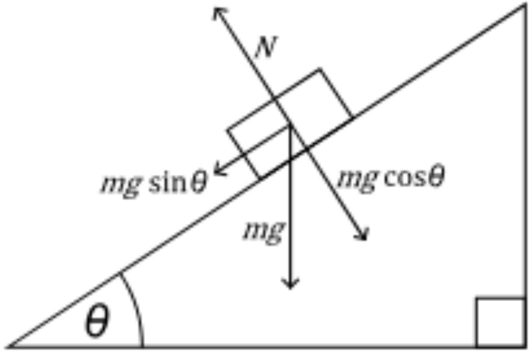
Does that "S" you are talking about have anything to do with the "S" in G = H – TS that they talk about in biology and chemistry?

– Biology major taking intro physics

Disciplinary languages

Dreyfus et al., *AJP* (2014)
Geller et al., *AJP* (2015)

Making IPLS relevant is not easy…



When I think of physics, I think of things I don't see in real life, like frictionless surfaces…

– Biology major taking intro physics

Disciplinary expectations and anxieties

Bialek, *Science* (2004)
Watkins et al., *PR-PER* (2012)
Kuo et al., *PR-PER* (2014)
Redish & Cooke, *CBE-LSE* (2013)

Making IPLS relevant is not easy…

I am not a physics person

- (many!) Biology majors taking intro physics

Personal identities as disciplinary scientists

Hall et al. *PhD Dissertation* (2011)
Sawtelle & Turpen, *PR-PER* (2015)

How have we tackled these challenges at Swarthmore?

Design principles for supporting relevance

- ❖ Foreground **authentic connections** between physics and the life sciences
- ❖ Expansive framing:

Watkins, Hall, Coffey, Cooke, and Redish, PRST-PER 2011.

Engle, Nguyen, and Mendelsohn, Instructional Science 39, *603 (2011).*

IPLS design principles

- ❖ Foreground **authentic connections** between physics and the life sciences
- ❖ Expansive framing: Telling as well as showing the **lasting value of what students learn** promotes transfer and enduring learning
- ❖ Use validated pedagogy!

Watkins, Hall, Coffey, Cooke, and Redish, PRST-PER 2011.

Engle, Nguyen, and Mendelsohn, Instructional Science 39, *603 (2011).*

IPLS design process

- ❖ Partner with disciplinary experts to identify **authentic connections**

Biology/biochemistry advisory committee

Rachel Merz
marine biologist
biomechanics

Kathy Siwicki
neurobiologist

Liz Vallen
cell biologist

Sara Hiebert Burch
physiologist

Kathleen Howard
biophysical chemist

Stephen Miller
structural biologist

(10% of entire STEM faculty)

SWARTHMORE

Name connections to other courses in class

Colleagues become advocates for our course

Rachel Merz
marine biologist
biomechanics

Kathy Siwicki
neurobiologist

Liz Vallen
cell biologist

Sara Hiebert Burch
physiologist

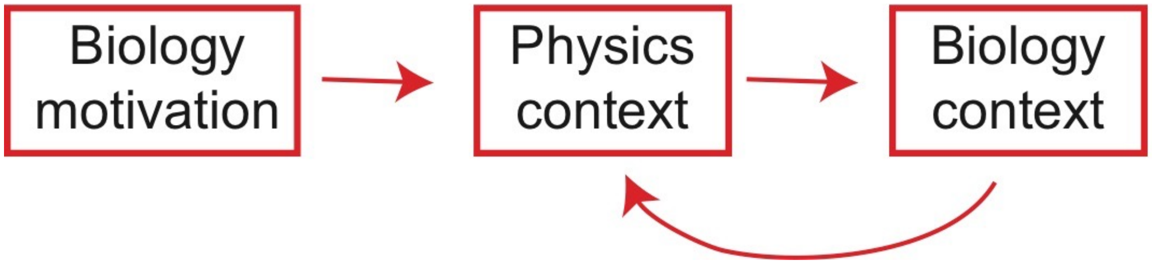
Kathleen Howard
biophysical chemist

Stephen Miller
structural biologist

SWARTHMORE

IPLS design process

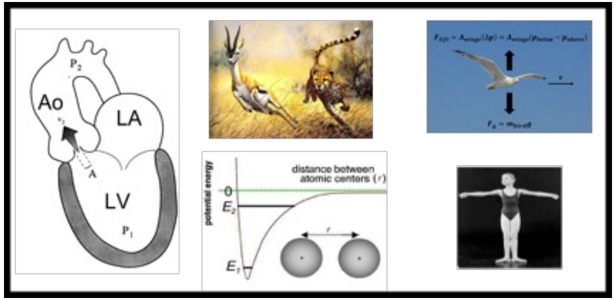
- ❖ Partner with disciplinary experts to identify **authentic connections**
- ❖ Build each course unit around connections



Reformed content with biological contexts

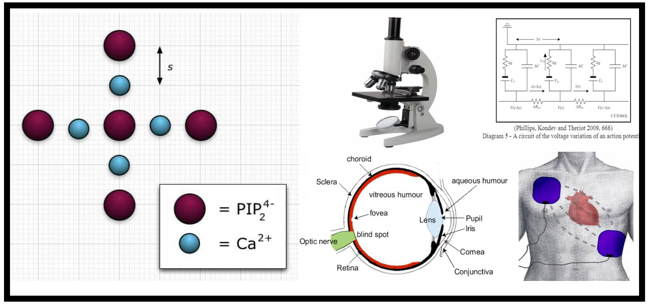
IPLS Mechanics

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



Reformed content with biological contexts

Cell Biology

IPLS Mechanics

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

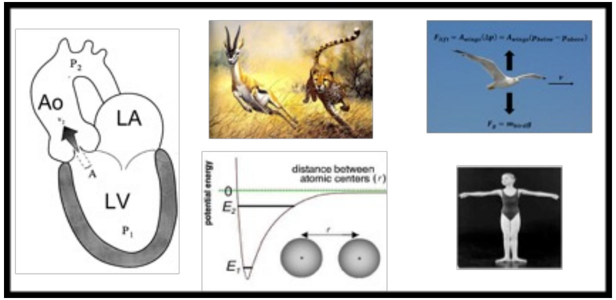
Animal Physiology

IPLS E&M

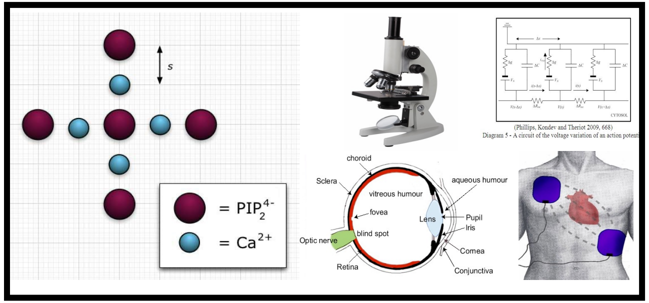
- Electricity/circuits: ***cell membrane, nerve signaling***
- Magnetism and induction: *magnetic sensing*, ***NMR***
- Optics: *animal vision and microscopy*
- Waves: *echolocation*

Neurobiology

(Bio)chemistry



SWARTHMORE



Reformed content with biological contexts

IPLS Mechanics

- Kinematics and Dynamics: ***random vs. coherent motion***, ***biomechanical stability***
- Energy: ***chemical energy***
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IPLS E&M

- Electricity/circuits: ***cell membrane, nerve signaling***
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- Optics: ***animal vision and microscopy***
- Waves: ***echolocation***

Cell Biology

Animal Physiology

Neurobiology

(Bio)chemistry

Curricula freely available at livingphysicsportal.org

Biological connections are integral, not tacked on

Today's talk

1. What is IPLS* and what are we trying to learn about it?

2. Interest and relevance

3. Do skills endure?

How does IPLS affect student attitudes to, interest in, and relevance of physics?

K. Ann Renninger
(Ed. Studies)

Panchompoo
Wisittanawat '13

SWARTHMORE

Comparing IPLS and standard instruction

For 2008-2015, only 2nd semester IPLS was offered

Compared pre-post changes in interest in and overall attitudes to physics for *same students* in

1st semester (standard mechanics)

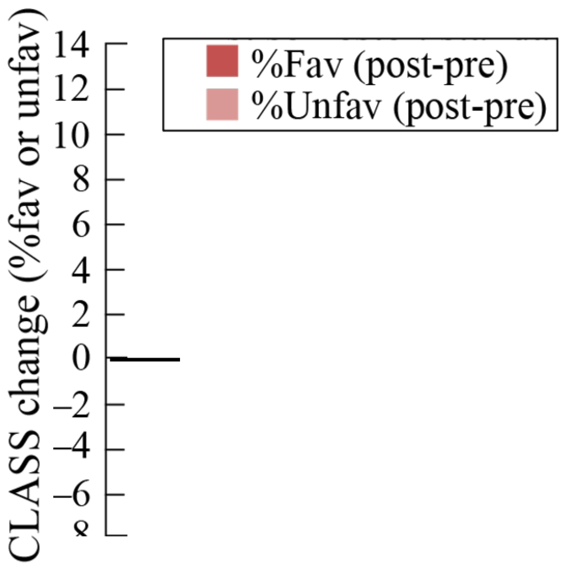
2nd semester (IPLS E&M)

Used CLASS as attitude measure

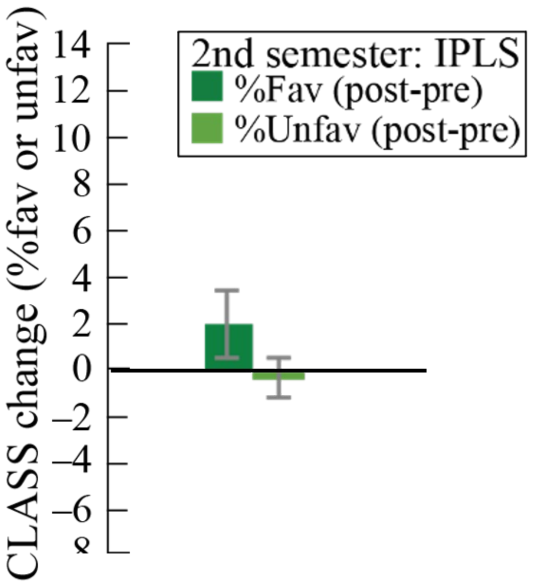
Adams et al., *PRPER* (2006)
Douglas et al., *PRPER* (2014)

Comparing attitude changes across courses

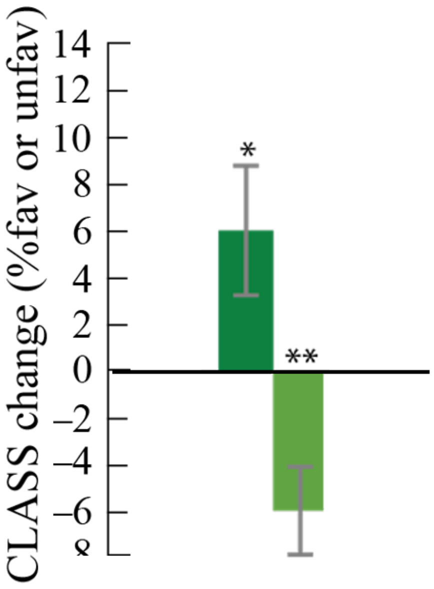
STANDARD



IPLS



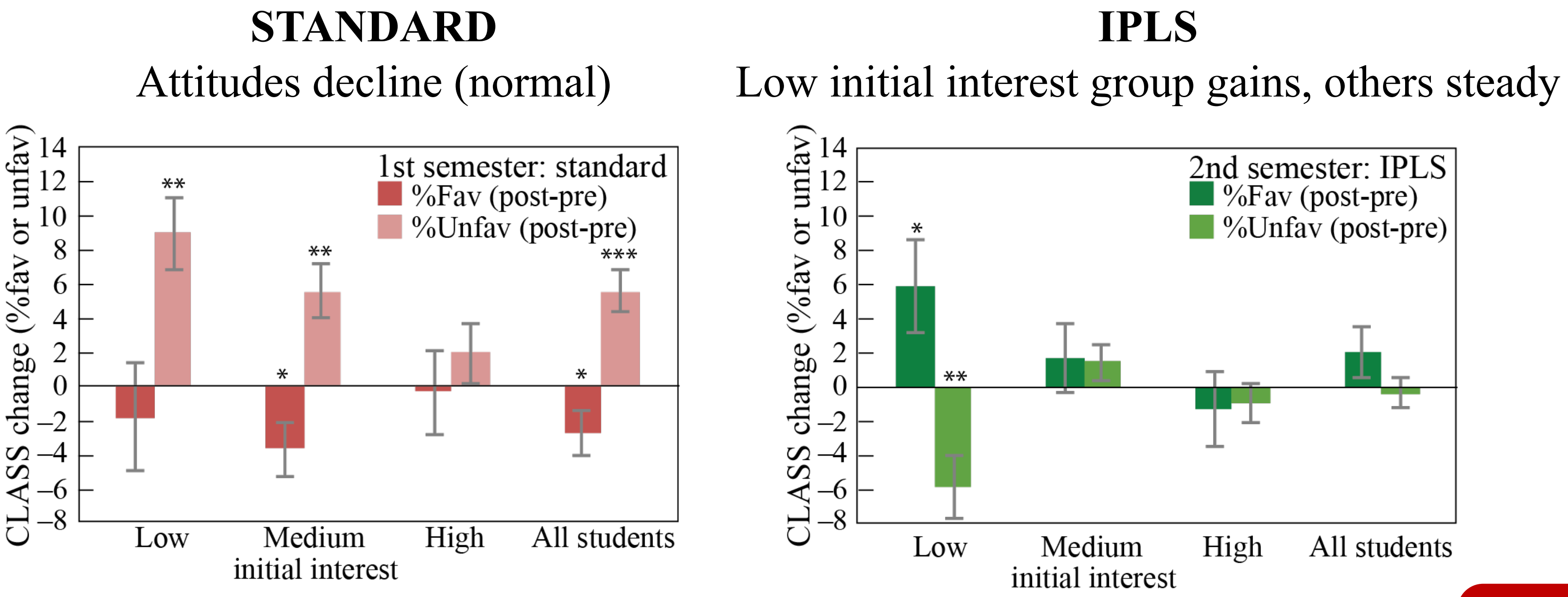
IPLS
(Low Initial Interest)



* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Crouch, Wisittanawat, Cai, and Renninger, PRPER 14, 010111 (2018).

Comparing attitude changes across courses



Fully matched sample ($N = 83$), aggregated across three years

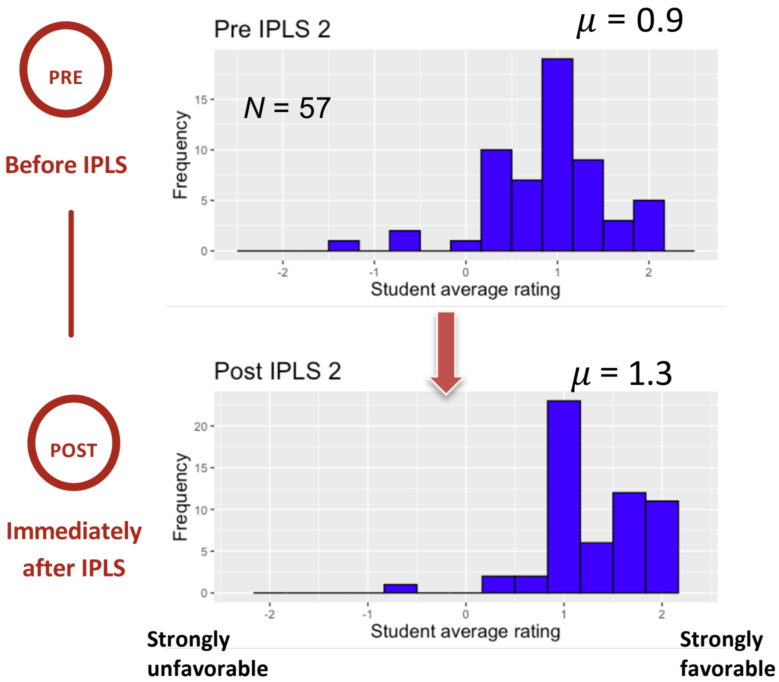
Crouch, Wisittanawat, Cai, and Renninger, PRPER 14, 010111 (2018).

Relevance

Students respond to 3 Likert-scale items about connections between physics and biology

Items from K. Hall, Ph.D thesis, UMd (2014).

Relevance of physics pre/post IPLS



Gwendolyn Rak
'22

Students view physics as much more connected to biology after one semester of IPLS

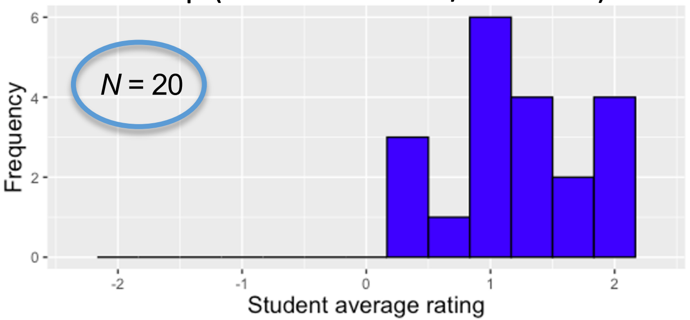
$p = 4 \times 10^{-5}$

(Wilcoxon signed-rank test)

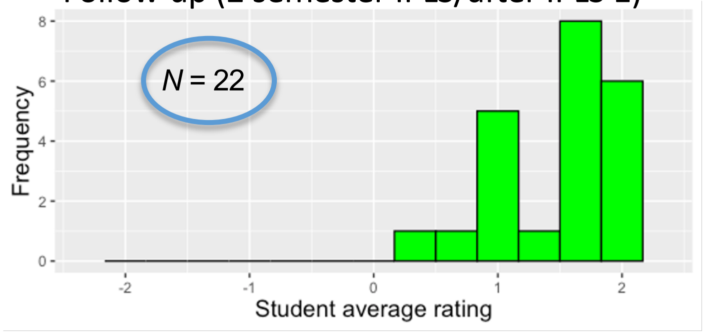
Items from K. Hall, Ph.D thesis, UMd (2014).

Greater relevance persists one year later

Follow-up (1 semester IPLS/no IPLS 1)



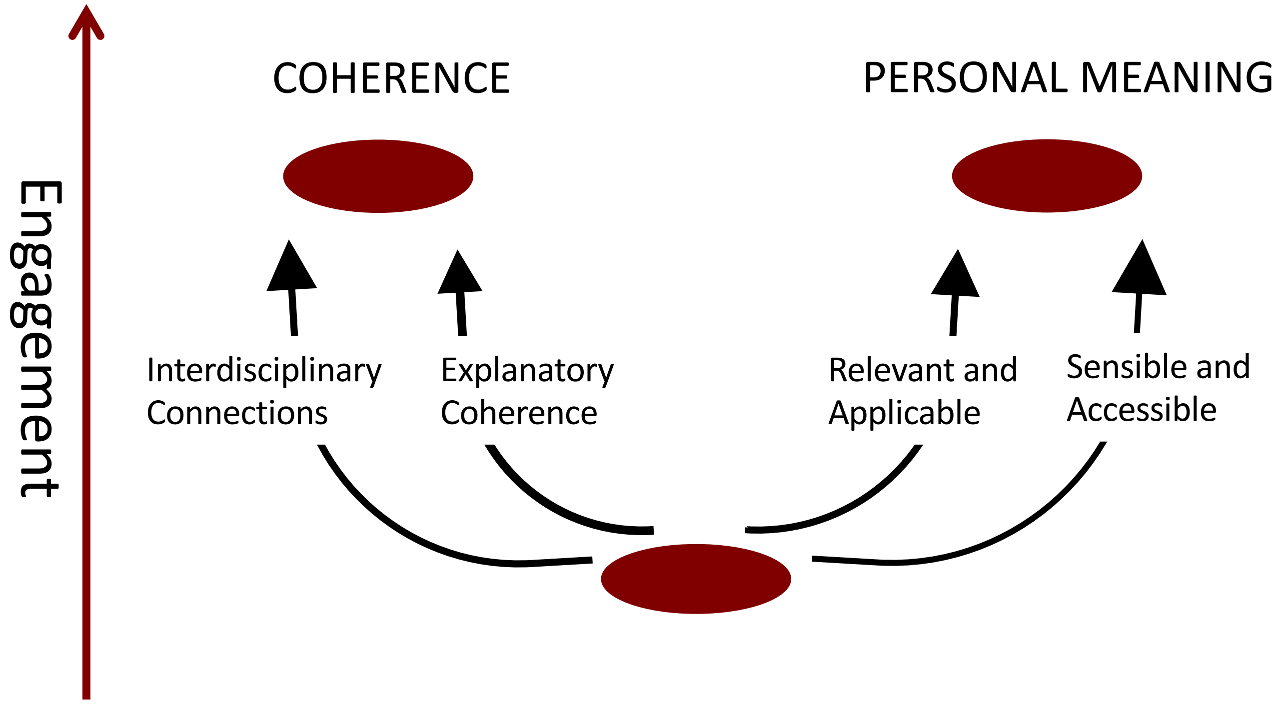
Follow-up (2 semester IPLS/after IPLS 1)



Post: μ = 1.3
Follow-up: μ = 1.2
} p-value=0.54

Post: μ = 1.5
Follow-up: μ = 1.5
} p-value=0.92

Engagement pathways as a way of characterizing student engagement in IPLS



Geller, Crouch, and Turpen, Phys Rev PER 14, 010118 (2018).

SWARTHMORE

Today's talk

1. What is IPLS* and what are we trying to learn about it?
2. Interest and relevance
3. **Do skills endure?**

Research question

NSF 1710875

How well can students use physics learned in IPLS to analyze a biological situation?

Research question

NSF 1710875

How well can students use physics learned in IPLS to analyze a biological situation presented in a biological setting?

Research question

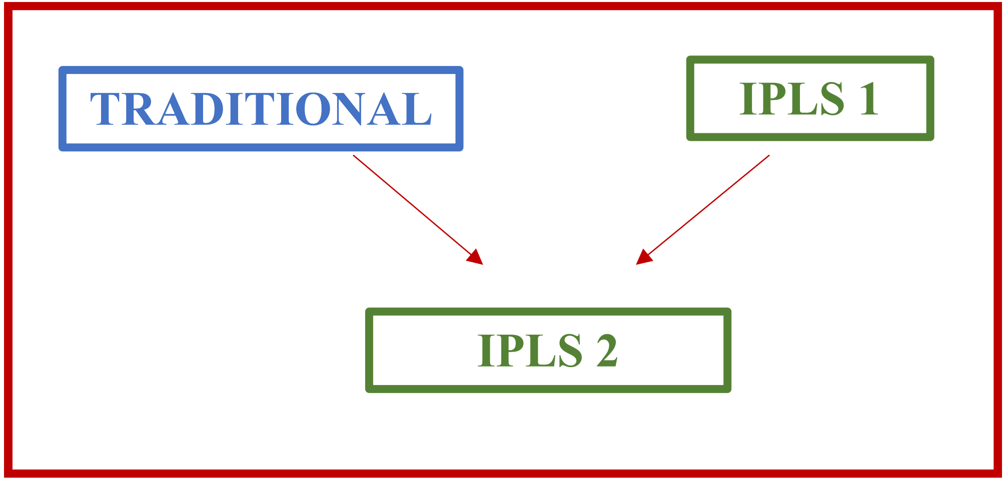
NSF 1710875

How well can students use physics learned in IPLS to analyze a biological situation presented in a biological setting and encountered (sometimes long) after the IPLS course ends?

A fortuitous curricular landscape at Swarthmore:

First Semester:
(Mechanics)

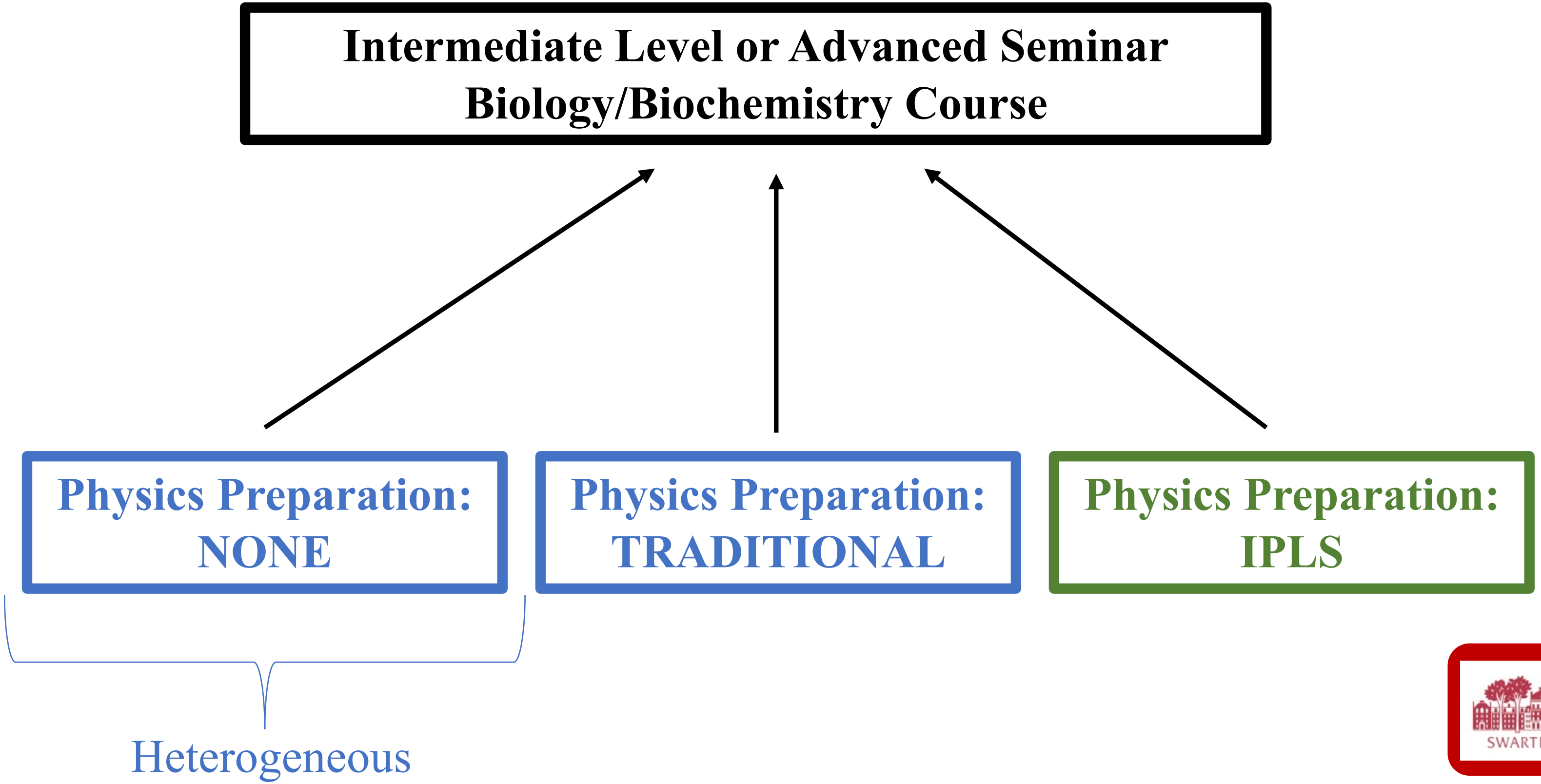
Second Semester:
(E&M)



IPLS students:

- mostly pre-med or life science majors
- mostly sophomores and juniors
- no formal biology or chemistry prerequisites, but most have taken courses in both areas.

Physics is not a *requirement* for the biology major at Swarthmore:



Core methodological challenge:

- How much input should we have in designing the embedded tasks?

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

YEARS 1 & 2
Embedded tasks with not researcher input

Core methodological challenge:

- How much input should we have in designing the embedded tasks?

LESS INPUT ⟷ **MORE INPUT**

Less input:

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

YEARS 3 & 4
Transfer task designed by research team in collaboration with Bio colleagues

More input:

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

Specific research question for this study:

Compared to their peers who did not take IPLS, are IPLS students in a biology capstone course ***more successful at coordinating between representations, and do they exhibit greater proficiency with mechanistic and general quantitative reasoning?***

Choice of the Biology Capstone Course*

All biology seniors take the course

- ~60% had taken at least *some* IPLS, ~40% had taken traditional or no physics
- ~40% had taken IPLS 1 specifically
- Task could be introduced as part of a general assessment of the quantitative course requirements in the biology department.

* Thank you to Michelle Smith at Cornell University for this methodological suggestion! We analyzed data from two iterations of the capstone course (Fall ’19 and Jan ’21).

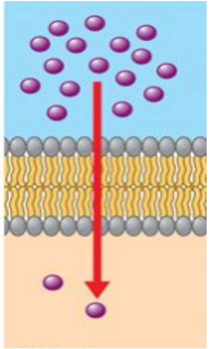
SWARTHMORE

Design of a Diffusion Task for the Biology Capstone

Why Diffusion?

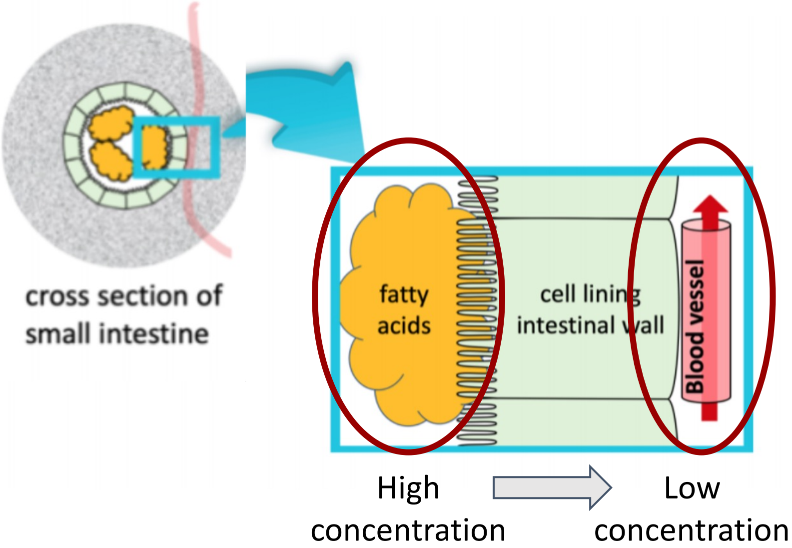
- Central physical concept for cell/molecular biology
- All biology students learn about diffusion at a phenomenological level
- Diffusion is discussed in IPLS 1 at a mechanistic level



SWARTHMORE

Design of a Diffusion Task for the Biology Capstone

Diffusion is presented in the context of animal digestion (not an IPLS context).



Students are asked to:

- Graph fatty acid concentration vs. position
- Describe the <u>**mechanism**</u> for diffusion
- Compare graphs and evaluate slopes
- Apply and reason with Fick's Law

Code for capstone task.

Skill	Evidence of skill	Rubric
Part I		
Converting a written description of a biophysical scenario into a qualitatively accurate graph	*Sketch of a graph that shows the fatty acid concentration to be constant in the intestine and the blood vessel, but linearly decreasing in the cell lining the intestinal wall*	• Ends: +0.5 for each constant (horizontal) end of the sketched line • Middle (QUANT): +2 points if linearly decreasing; +1 if decreasing, but not linearly • For bar plot or scatter plot instead of a continuous graph: +1 if trend is correct
Providing a mechanistic, molecular-level explanation for the flow of molecules down a concentration gradient	*Mechanistic explanation for the net flow of particles from high to low concentration in terms of the difference in number of particles moving randomly in different regions of the system, along with a supporting diagram.*	Explanation (IPLS 1): • +2: Difference in number of molecules between high and low concentration regions used to provide a mechanism for the net flow of particles, even though each individual molecule moves randomly • +1: Explains the flow in terms of general physical reasoning (collisions, thermodynamics, Fick's law), but does not employ a complete mechanistic explanation • 0: Restates the question or no coherent explanation Diagram (IPLS 1): • +1: Diagram demonstrates why more molecules move across a boundary from high to low concentration than from low to high concentration • +0.5: Diagram is present, but does not clearly articulate the above idea • 0: No diagram
Part II		
Skill	Evidence of skill	Rubric
Calculating rates of diffusion from graphical representations of concentration as a function of position.	*Calculation of slopes from the data provided, and comparison of these slopes to rank diffusion rates*	Correctness (QUANT): • +2: Completely correct ranking: $B > A = D > C$. • +1: Slope B is steepest and slope C is least steep, but slopes A and D are not identified as having the same slope • 0: Other ranking Slope reasoning (QUANT): • +2: Correct reasoning with slopes • +1: Incorrect calculation or incomplete explanation with slopes • +0 + 0: No evidence of reasoning with slopes
Part III		
Skill	Evidence of skill	Rubric
Relating the mathematical expression of Fick's law to the physical process of molecules moving from areas	*Explanation that explicitly relates the minus sign in Fick's law to the direction of molecular movement through the concentration gradient*	• (QUANT) +1: The minus sign is needed to specify direction of flux

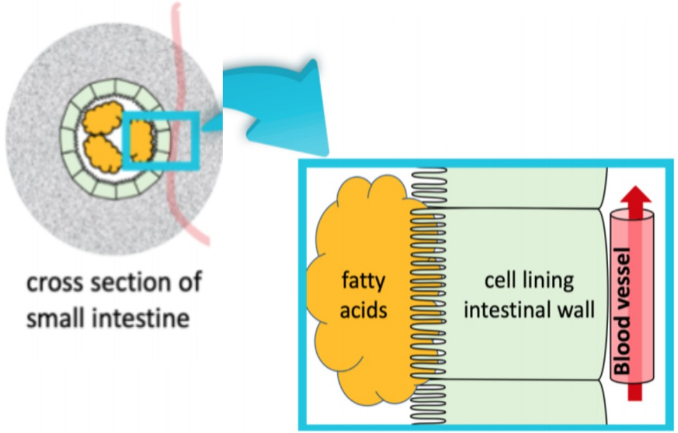


TABLE II. *(Continued)*

Skill	Evidence of skill	Rubric
Part I		
Converting a graphical representation of diffusion into a quantitative, symbolic representation (Fick's law) that can be applied to obtain a quantitative result	*Using Fick's Law to calculate a rate of flux, including appropriate units, from graphical data provided; explicitly coordinating the minus sign in Fick's law with a spatial direction*	End regions (QUANT): • +1: Identifies the ends as $J = 0$ Middle region (QUANT): • +1: Calculation for the middle as $J = 10\,000$ molecules/s • +1: Positive sign obtained by correct use of Fick's law Holistic over all of Part III (IPLS 1): • +2: Coordinates the positive sign to the direction of flow along the x axis • +1: Attempts to relate the sign to the coordinate system, but unsuccessfully

Emergent coding scheme

Content and Skills Emphasized in IPLS 1

- Mechanistic description of diffusion
- Coordinating multiple representations of diffusion
- Coordinating the sign of particle flux with a direction in space

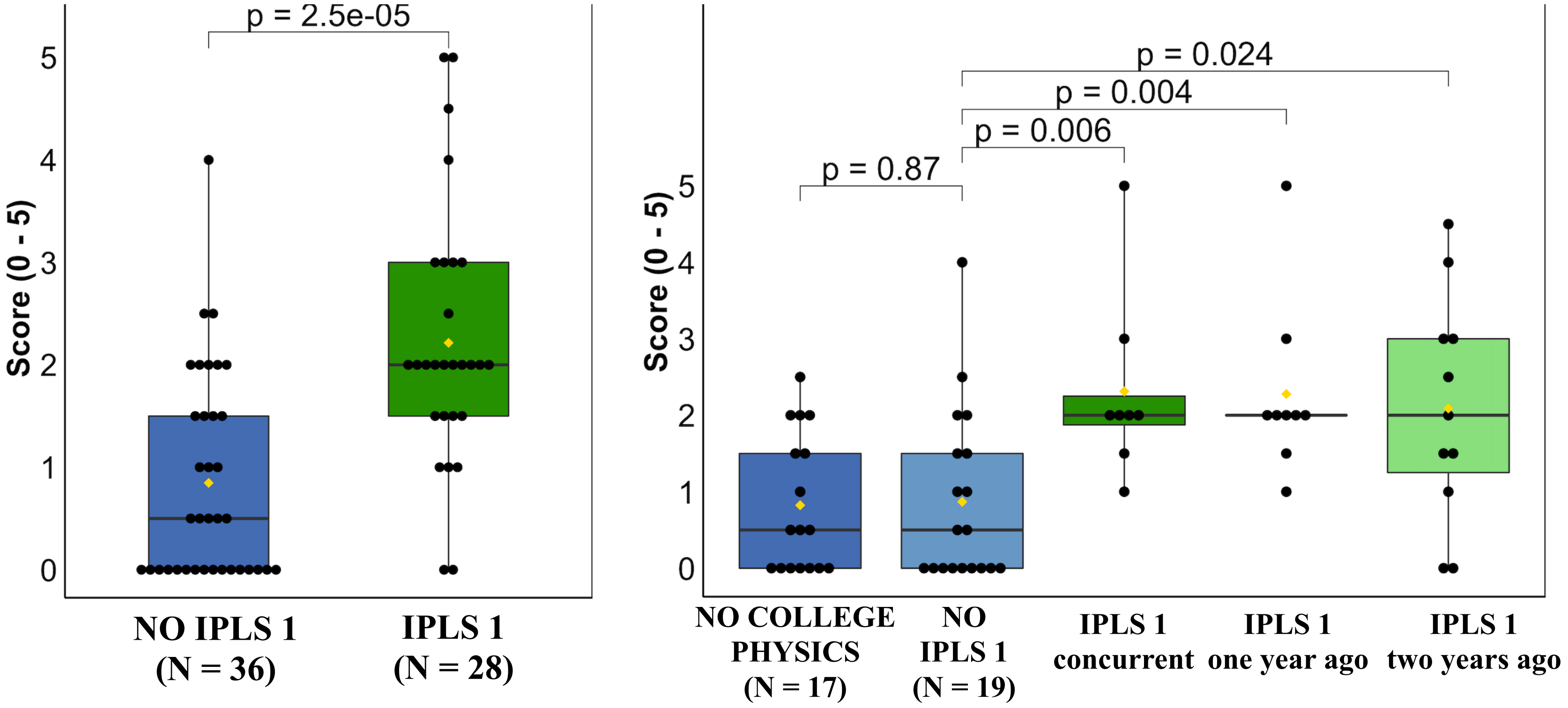
General Quantitative Skills Emphasized in IPLS (and elsewhere)

- Draw linearly decreasing graph
- Compare graphs by their slopes
- Use equations to calculate relevant quantities
- Reason with units

Jack Rubien ’20

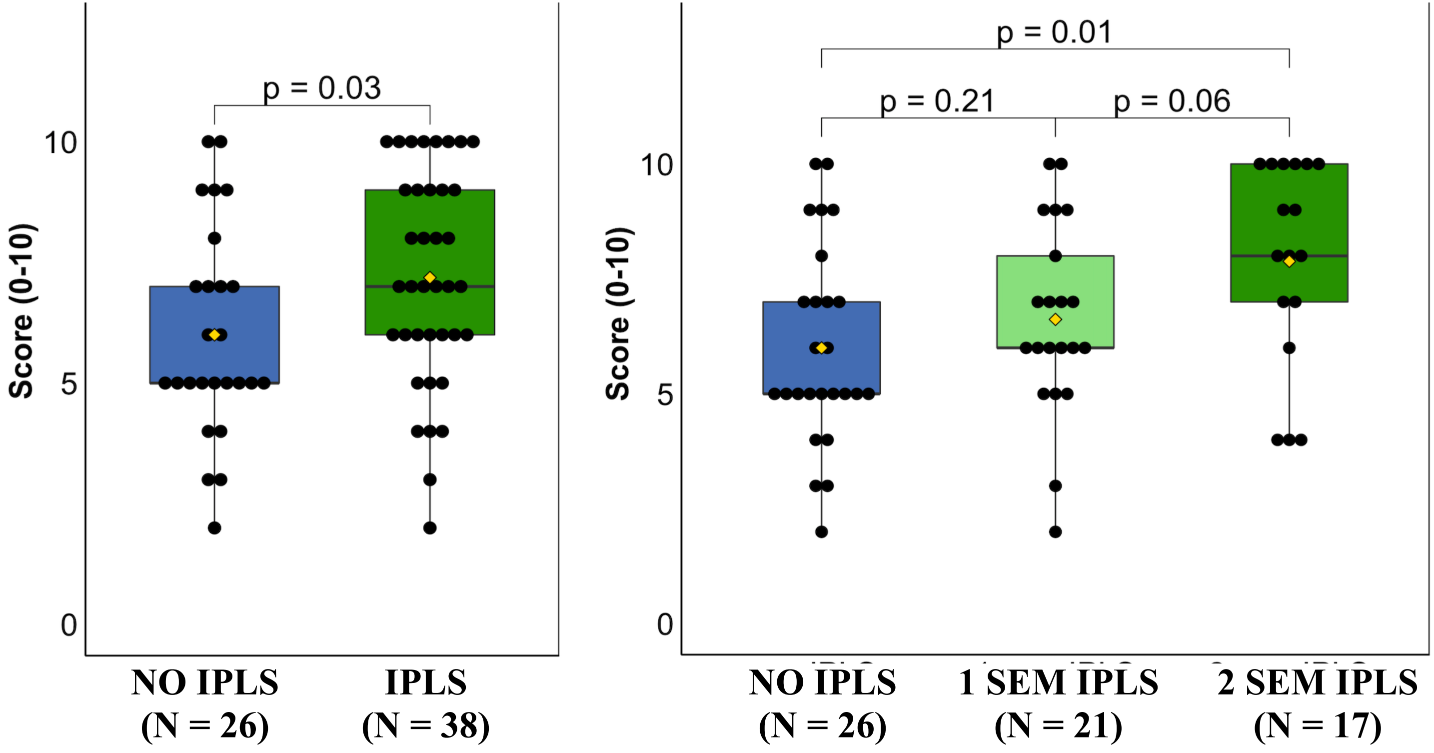
Cohen’s kappa > 0.8 for all elements

Content and skills emphasized in IPLS 1



Geller et al., *PR-PER* (2022)

General quantitative skills



Geller et al., *PR-PER* (2022)

Are IPLS students just higher performing?

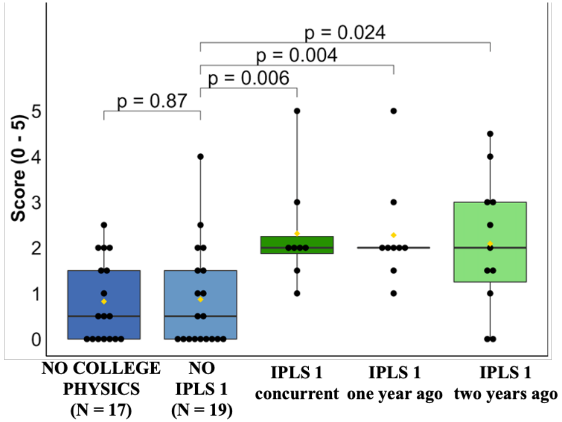
NO

IPLS students had lower overall GPA in STEM courses than the non-IPLS students.

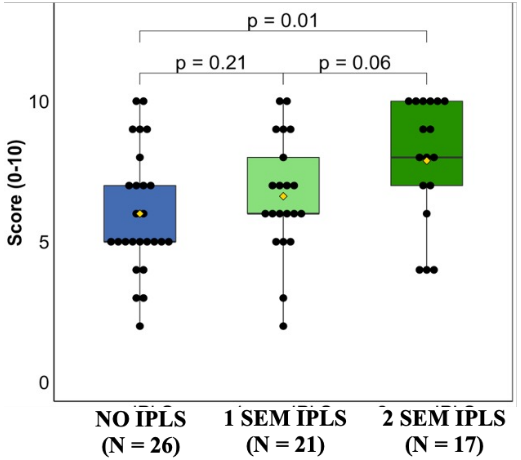
Code elements	Observed difference in mean $\Delta\mu$	Adjusted difference in mean
IPLS 1-specific	$\mu_{\text{IPLS1}} - \mu_{\text{non-IPLS1}} = \mathbf{1.36}$	1.50 (+**0.14**)
General quantitative	$\mu_{\text{IPLS1}} - \mu_{\text{non-IPLS1}} = \mathbf{1.18}$	1.19 (+**0.01**)

Geller et al., *PR-PER* (2022)

Conclusion I: **IPLS 1 students successfully reason about diffusion in a novel biological context, even after 2+ years**



Conclusion 2: **IPLS students demonstrate greater proficiency with quantitative reasoning in a biology context**



Takeaways

IPLS students:

- ❖ Gain interest via multiple engagement pathways
- ❖ Gain enduring sense of relevance of physics to biology
- ❖ Successfully reason about diffusion in a novel biological context, even after 2+ years
- ❖ Demonstrate greater proficiency with quantitative reasoning in a biology context

Today's talk

1. What is IPLS* and what are we trying to learn about it?
2. Interest and relevance
3. Do skills endure?
4. **Current study: How does the course produce these outcomes?**

*__IPLS__ = **I**ntroductory **P**hysics for **L**ife **S**ciences

Small school takeaways

- ❖ Curriculum development and PER can synergize
- ❖ Leverage deep relationships with students and colleagues

Downstream outcomes

IPLS efforts at Swarthmore:

- ❖ Strengthened faculty partnerships
  → later Inclusive Excellence efforts
- ❖ Synergized with existing College goals (HHMI grant)
  → resources

Thank you to.....

Sara Hiebert Burch (Biology)

Ann Renninger (Educational Studies)

Chandra Turpen

Project advisors:

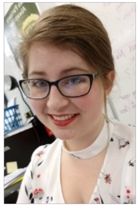
Andrew Boudreaux, Todd Cooke, Eric Brewe, Eric Kuo, Tim Nokes-Malach, Sanjay Rebello, Laura Rios

Stephen Hackler (Swarthmore Physics)

Andrew Mason, Carina Rebello, Tianlong Zu (PERC organizers)

Jack Rubien '20

Jonathan Solomon '20

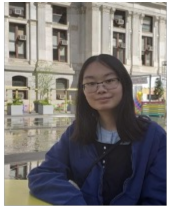


Haley Gerardi '17

Aqil MacMood '20

NSF 1710875

NSF 2142074



Angelina Tjia '26

Maya Tipton '23

Gwendolyn Rak '22

Nathaniel Peters '18

Panchompoo Wisittanawat '13

Drake Roth '25

Nikhil Tignor '24

Rain White'24

Brandon Daniel-Morales '24

Lundy Zheng '26

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