Assessing the impact of IPLS on physical reasoning

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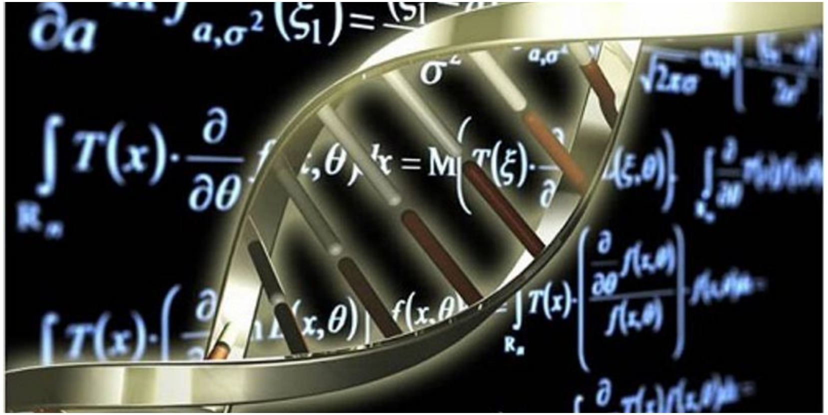
What is IPLS? (Introductory Physics for Life Sciences)

- Introductory Mechanics and E&M courses **designed to engage and equip life science students to use physics in future contexts**[1]

- Interdisciplinary connections and modeling are central to the course



[1] C. H. Crouch & K. Heller (2014)

Context: IPLS and Life Sciences at Swarthmore

Undergraduate-only liberal arts college in PA

- ~1600 students
- ~1 in 3 involved in life sciences, including majors, minors, and pre-med track

Offers year-long IPLS course and year-long traditional introductory physics course

Research Question

Compared to their peers with traditional introductory physics, **are IPLS students better equipped to flexibly apply physical models in unfamiliar biological contexts?**

Data Sources

Population 1:

life science students taking **IPLS mechanics**

N = 61

Population 2:

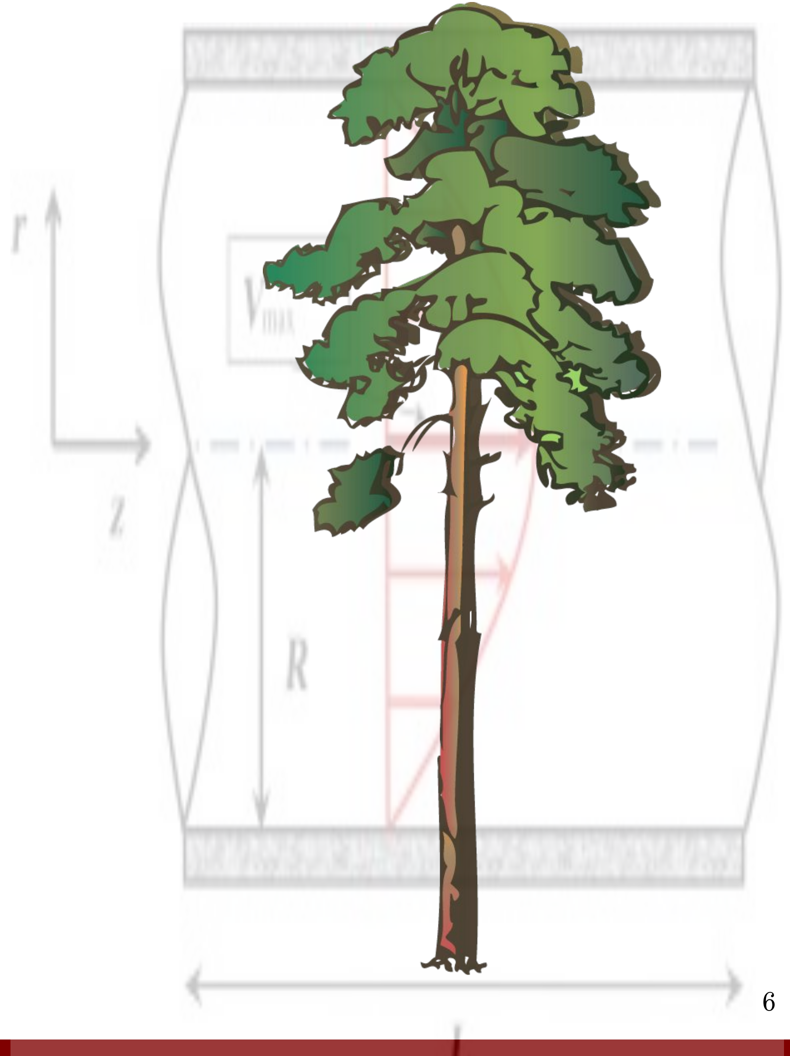
life science students taking **traditional mechanics**

N = 37

Task Design

Applying physics studied in both courses to model an unfamiliar biological situation

Model fluid dynamics of sap pressure: choice between viscous/non-viscous model and addition of gravity



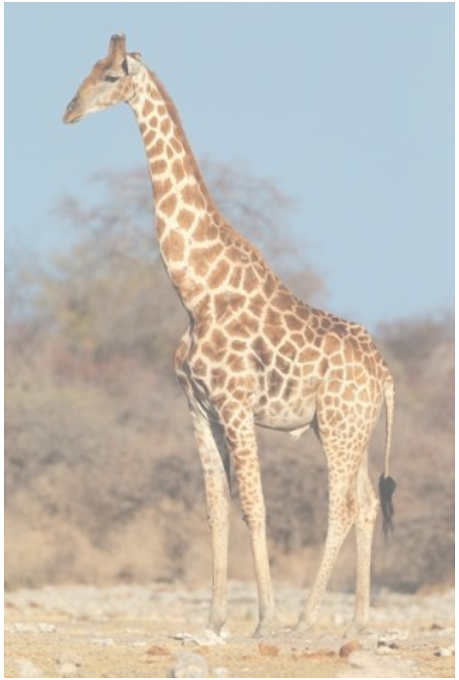
This is hard!

Part (a): Implementing a simple model

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** … s neck is extended … om the picture pr…

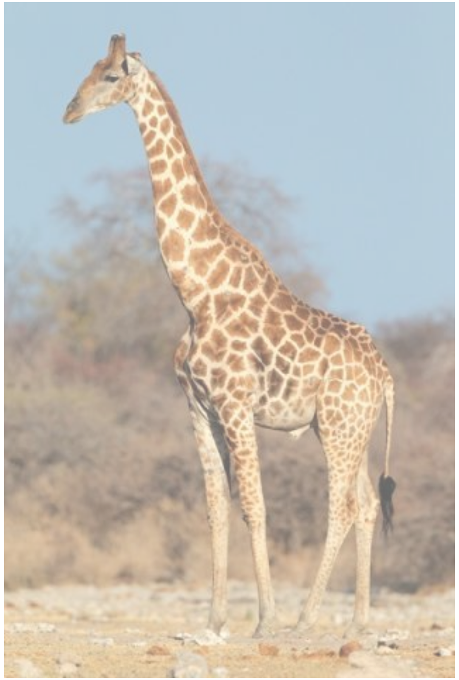
Purpose: to prime students to think about role of gravity in fluid pressure in the main task

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



Part (a): Implementing a simple model

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.



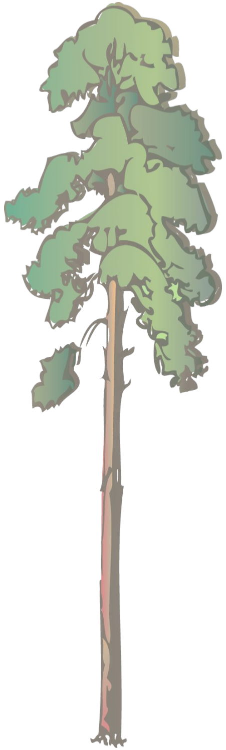
Please briefly explain your reasoning, including how you decided which equations to use, and any approximations you made.

Part (b): Justifying and flexibly combing models

"...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."



Part (b): Justifying and flexibly combing models

“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

ste … essure of water in the xylem to

no … re…”

Physical clue to use viscous model (Hagen-Poiseuille) over non-viscous model (Bernoulli)

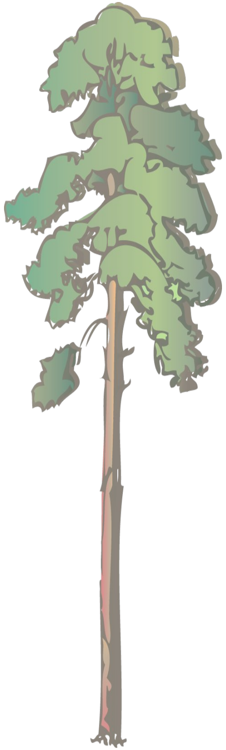
Part (b): Justifying and flexibly combing models

"...Consider a tree in w iameter xylem at a
volume flow rate of 1. 0.40 mL/hr),
corresponding to an av pressure in the
roots is equal to atmos
what is the pressure at nk?

Students should...

1. **Identify and justify model choice (viscous/non-viscous)**
2. **Combine effect of gravity**

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.***"



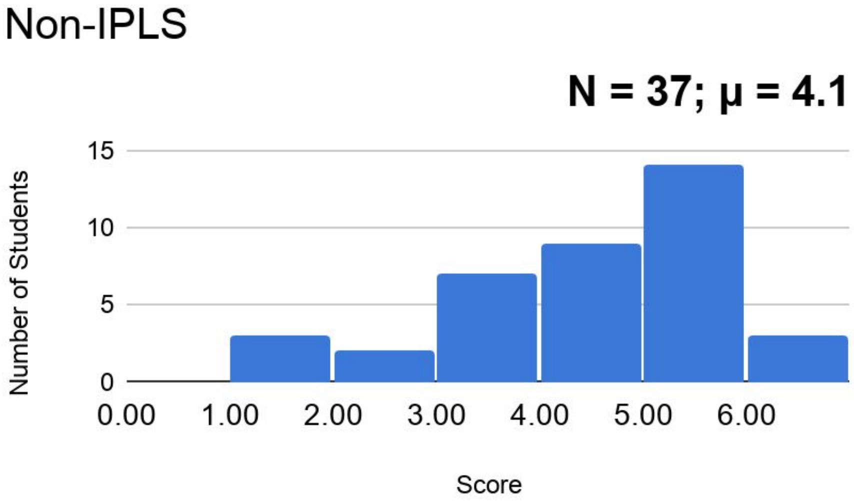
Coding for elements of modeling

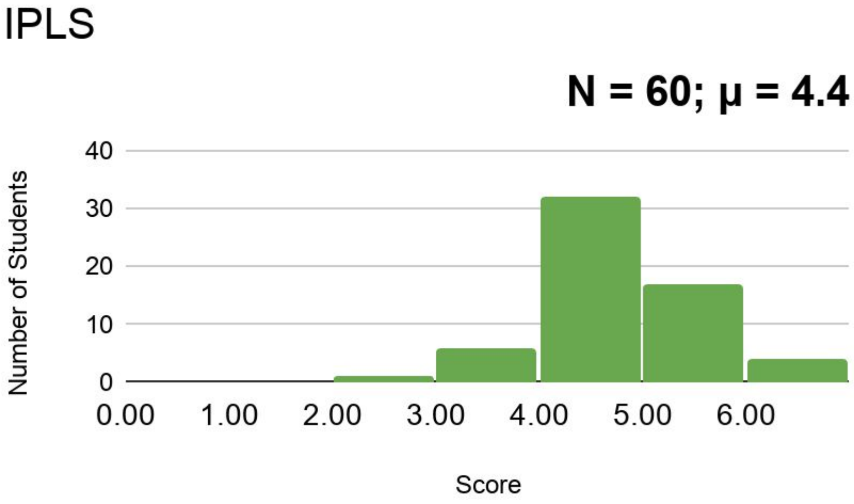
Three different researchers **iteratively** developed an emergent code that identified key modeling and problem-solving competencies, including

- **Model justification**
- **Flexible coordination of physical models**
- **Units and calculation**

Inter-rater reliability: 0.94

Implementing a simple model: similar outcomes for both populations

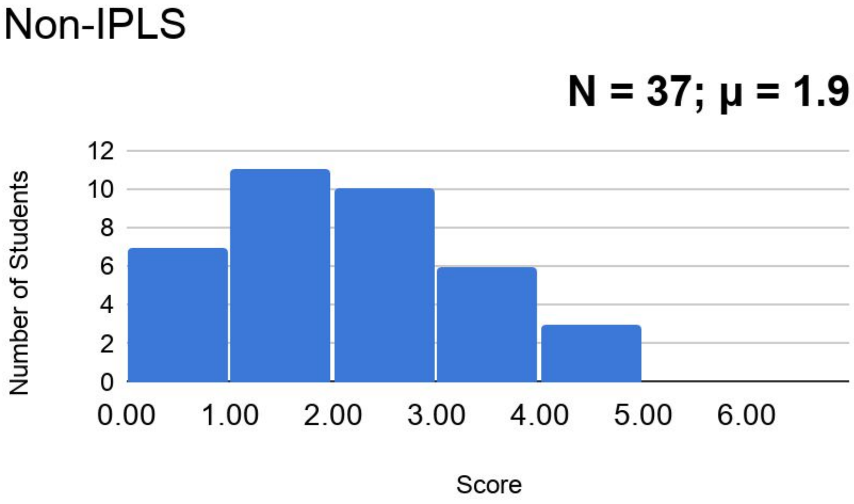


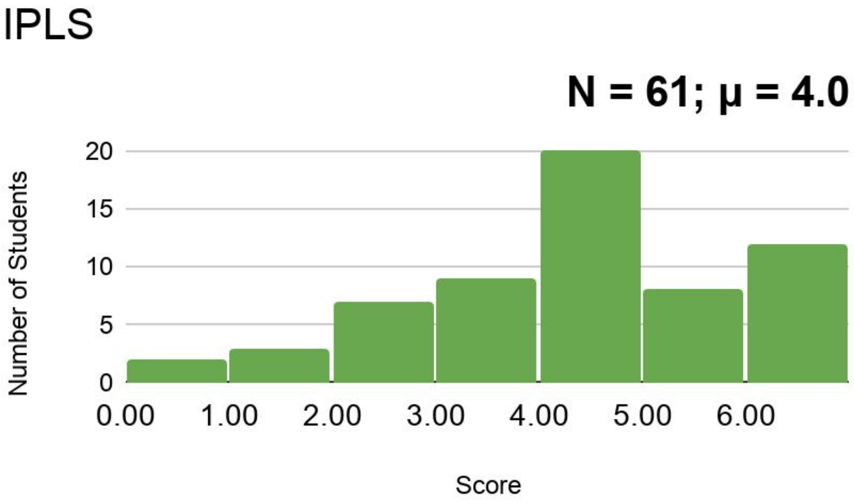


p = 0.20

(Unpaired t-test)

Justifying and flexibly combining models: IPLS students perform more favorably

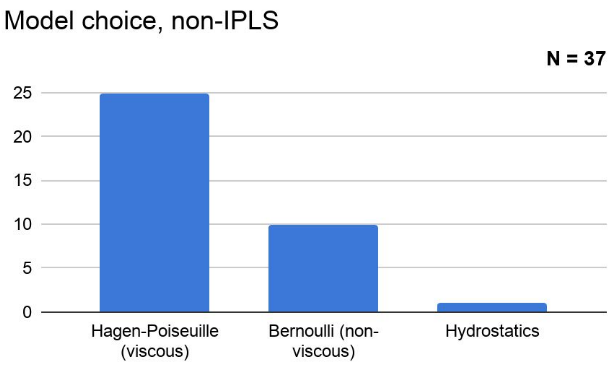


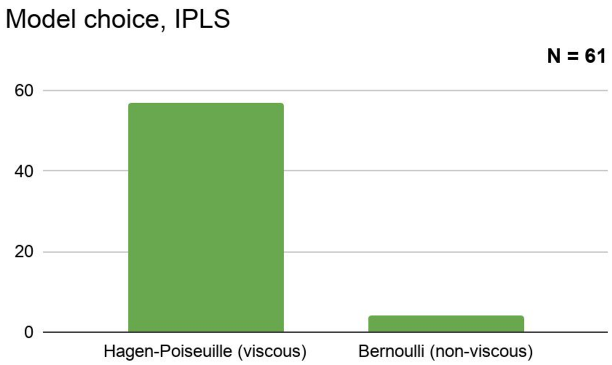


$p < 0.001$

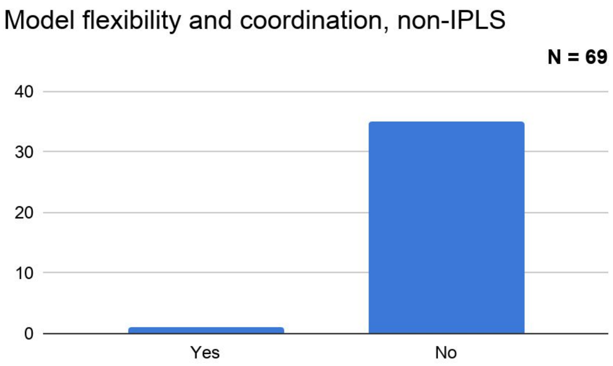
(Unpaired t-test)

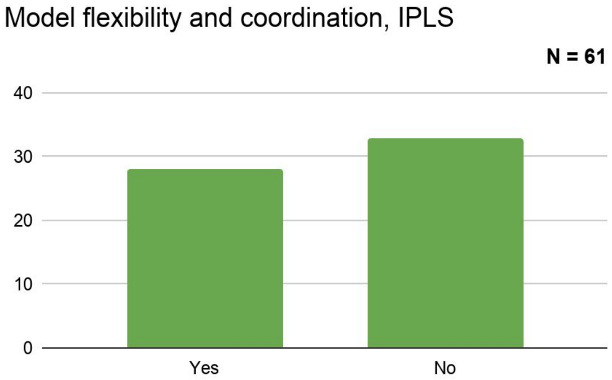
1. IPLS students were more likely to choose the correct model,...



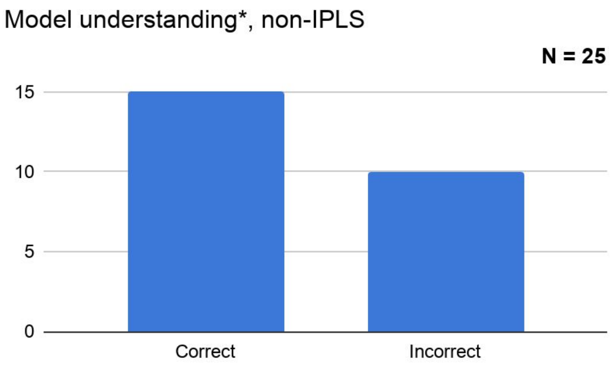


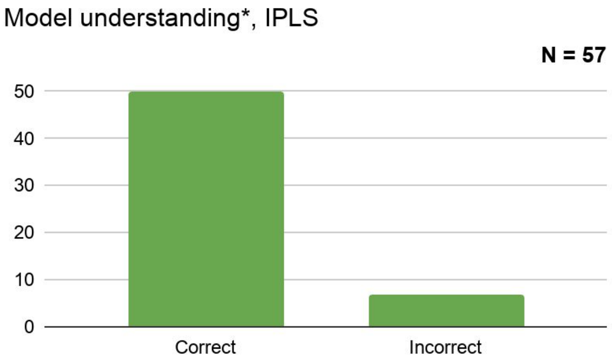
2. ...combine the effects of viscosity and gravity,





3. ...and identify that pressure decreases with height.





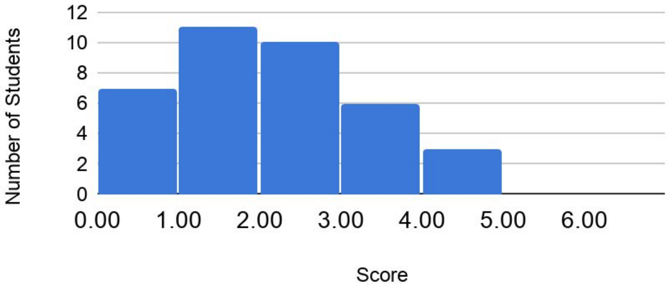
*of the students who choose the viscous model

Removing the inclusion of the gravity term from the code, **IPLS students still perform more favorably.**

Original code

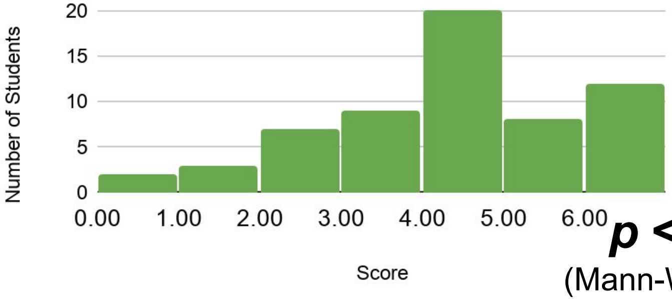
Non-IPLS

N = 37; μ = 1.9



IPLS

N = 61; μ = 4.0

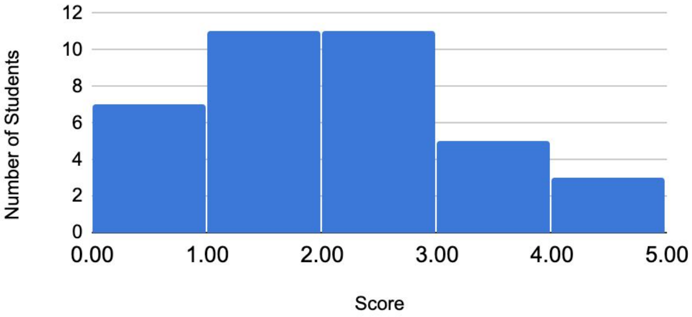


$p < 0.001$
(Mann-Whitney Test)

Code, gravity removed

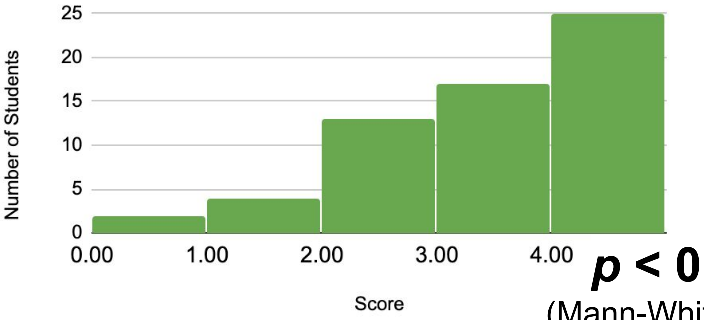
Non-IPLS

N = 61; μ = 1.8



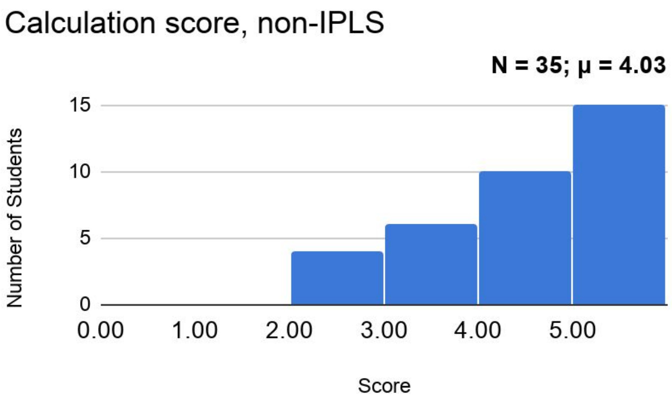
IPLS

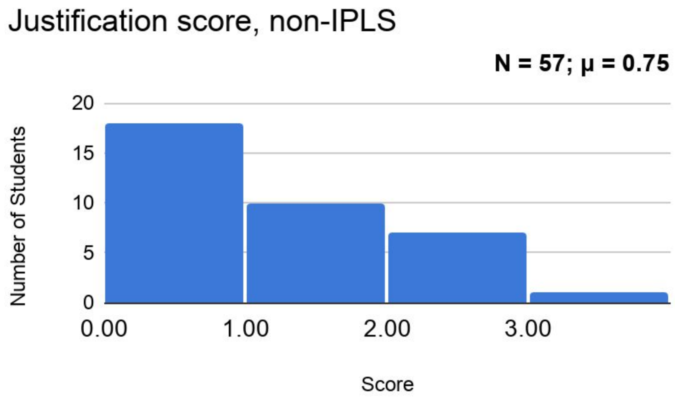
N = 37; μ = 3.0

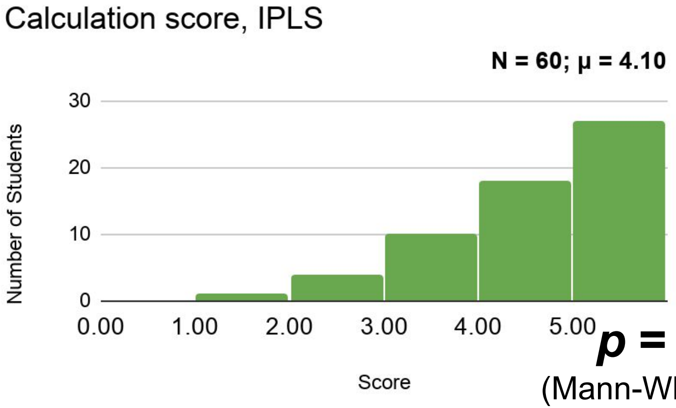


$p < 0.001$
(Mann-Whitney Test)

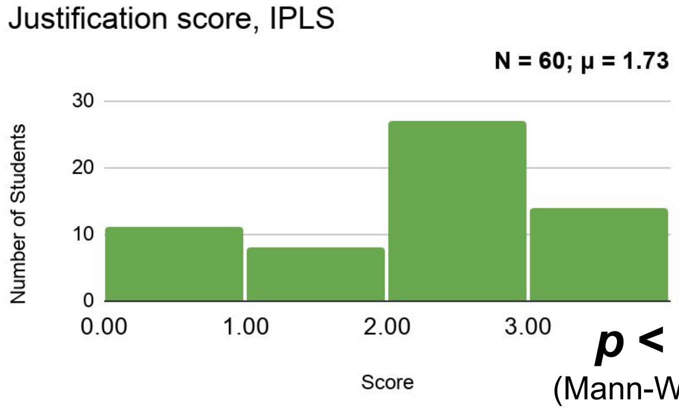
IPLS and non-IPLS students demonstrate comparable numerical skill but IPLS students are more likely to justify their modeling choices.







p = 0.76
(Mann-Whitney test)



p < 0.001
(Mann-Whitney test)

Are IPLS students better equipped to use physical models in contexts that require reasoning with physical ideas that are introduced for the first time in the task?

Part (c): Applying an unfamiliar physical concept

"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 in cohesive substances such as liquids. Just as for positive pressures, a pressure difference across a surface corresponds to a force…."

Purpose: probe ability to reason with newly introduced physical concepts[1]

[1] Inspired by J. D. Bransford & D. L. Schwartz (2001)

Part (c): Applying an unfamiliar physical concept

"...A critical difference between the fluid transport systems of trees and animals like giraffes is that blood ves of a stretchy material, while the xyler very rigid material.

Do students correctly articulate that the xylem rigidity enables the tree to withstand negative pressure?

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."***

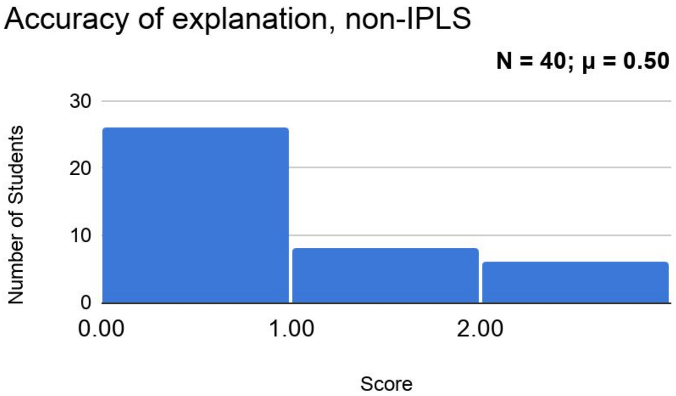
Coding for complete explanations

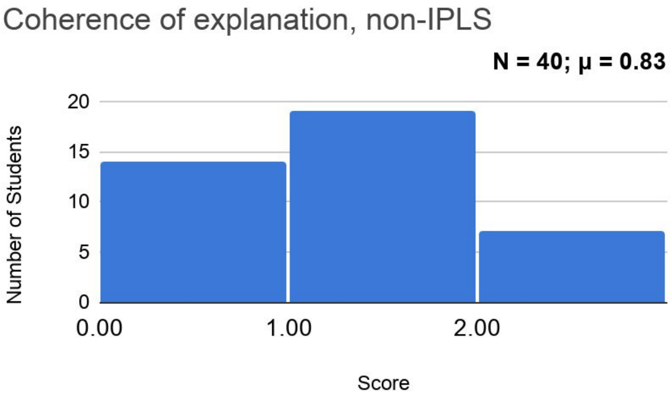
- **Accuracy**: whether the explanation is correct and useful in the context

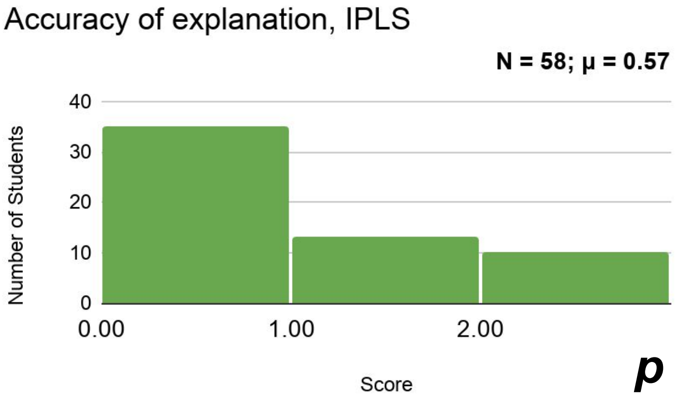
- **Coherence**: relating to the quality of the reasoning

Inter-rater reliability: 0.89

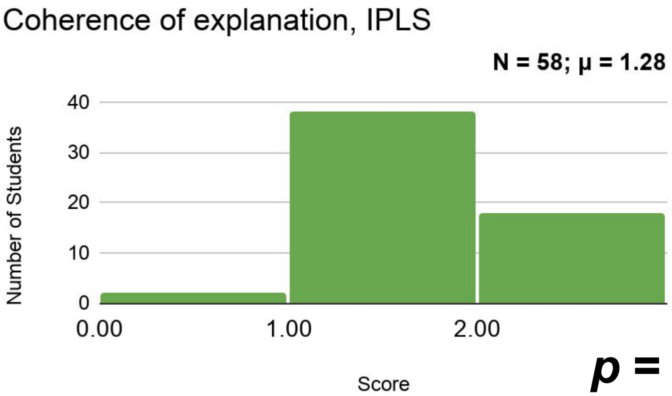
IPLS and non-IPLS students score similarly on accuracy but IPLS students have higher coherence scores.







p = 0.70
(Mann-Whitney test)



p = 0.0031
(Mann-Whitney test)

Conclusions

1. IPLS students demonstrate **greater skill in flexibly applying physical models and justifying their reasoning** in *unfamiliar biological contexts.*

2. IPLS students are more likely to **create coherent explanations** requiring reasoning about *physical ideas they had not seen previously.*

Acknowledgements

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