Physics Quantitative Literacy:

Assessment and Interaction with Student Characteristics

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Overview

- Introduction to Physics Education Research
- What is the role of inventories?
- Example: Concept inventory
- Reasoning inventories, PIQL
- Research question
- Method: Hierarchical Linear Modeling
- Results and conclusion

Physics Education Research

- Discipline-based research
- Coordination of curriculum development, research and instruction
- PEG: Pioneer in Physics Education Research

Research Curriculum Physics Education Group Instruction

Background: Concept Inventory

- Assessment of conceptual understanding
- Provide tool for researchers and instructors to assess impact of curricular interventions
- 1990s introduction of concept inventories led to widespread improvement of quality of physics instruction and curricula
- Example: Force Concept Inventory (FCI)

Background: Concept Inventory

A stone dropped from the roof of a single story building to the surface of the earth:

(A) reaches a maximum speed quite soon after release and then falls at a constant speed thereafter.

(B) speeds up as it falls because the gravitational attraction gets considerably stronger as the stone gets closer to the earth.

(C) speeds up because of an almost constant force of gravity acting upon it.

(D) falls because of the natural tendency of all objects to rest on the surface of the earth.

(E) falls because of the combined effects of the force of gravity pushing it downward and the force of the air pushing it downward.

Quantitative Literacy

Quantitative Literacy: A set of interconnected skills, attitudes, and habits of mind that together support the sophisticated use of elementary mathematics to describe and understand the world.

E.g. Nurses need to reason about ratios and proportions when dosing patients

Physics Quantitative Literacy (PQL): Quantitative literacy in the context of introductory physics, characterized by the blending of conceptual and procedural mathematics to generate and apply models relating physics quantities to each other.

Assessing PQL

- There are few resources to assess PQL
- Suzanne Brahmia's group is developing the Physics Inventory of Quantitative Literacy (PIQL)
- This is a *reasoning* inventory, rather than a concept inventory
- Concept inventories are course-specific, whereas reasoning develops throughout the curriculum and assessed beyond a single course

Equations as Storytelling

To an expert, a physics equation "tells the story" of an interaction or process.

$$x(t) = 40m + \left(-5\frac{m}{s}\right)t + \frac{1}{2}\left(-9.8\frac{m}{s^2}\right)t^2$$

- Experts will quickly construct a mental story of the co-variation of position and time of a projectile that starts at 40 m above the ground and is launched with a speed of 5 m/s vertically downward
- Part of the challenge of learning physics is developing the ability to decode symbolic representations in this manner
- Positive and negative signs pose particular decoding challenges for physics students

Categories of Quantitative Literacy

Proportional reasoning: the use of ratios and products to describe systems and characterize phenomena

Covariational reasoning: holding in mind invariant relationships among quantities' values as they vary in dynamic situations

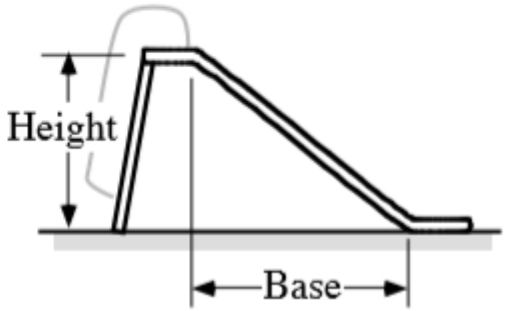
Reasoning about signed quantities: the use of sign to describe systems and characterize phenomena (negative/positive)

PIQL Question

You are purchasing a slide for a playground and would like to get the steepest one you can find. For four different slides, you have the measurements of the length of the base of the slide (measured along the ground), and the height of the slide.
You decide to use this information to rank the slides from **most steep** to **least steep.** Which of the following choices is the best ranking?

a. $A > B = C > D$
b. $B > C > A > D$
c. $A = B > C > D$
d. $B > A = C > D$
e. $A = D > C > B$

Slide	Base	Height
A	8 ft	12 ft
B	5 ft	9 ft
C	6 ft	9 ft
D	12 ft	8 ft



Negative Work

A hand exerts a constant, horizontal force on a block as the block moves along a frictionless, horizontal surface. No other objects do work on the block. For a particular interval of the motion, the hand does $W = -2.7$ J of work on the block. Recall that for a constant force, $W = \vec{F} \cdot \Delta\vec{s}$.
Consider the following statements about this situation. Select the statements(s) that must be true. ***Choose all that apply.***

a. The work done by the hand is in the negative direction.

b. The force exerted by the hand is in the negative direction.

c. The displacement of the block is in the negative direction.

d. **The force exerted by the hand is in the direction *opposite* to the block's displacement.**

e. The force exerted by the hand is in the direction *parallel* to the block's displacement.

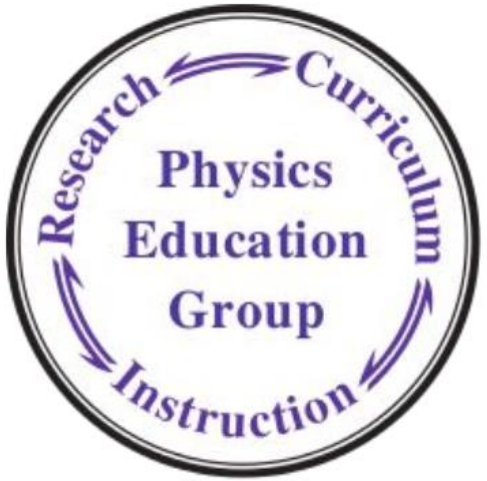
f. Energy was added to the block system.

g. **Energy was taken away from the block system.**

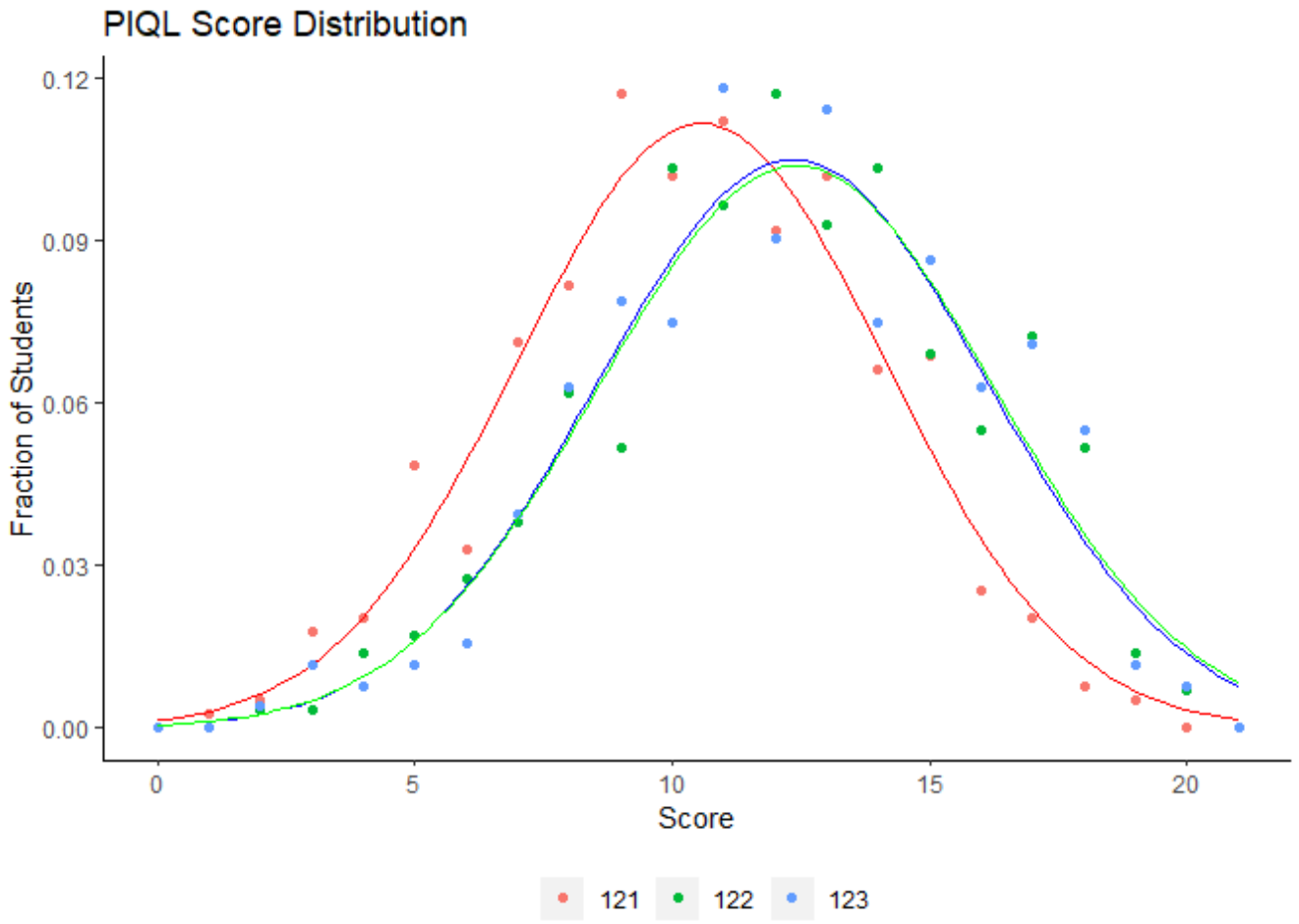
The PIQL Goals

- Align with growth mindset
- Improve sophisticated quantitative literacy
- Broaden participation in math-based STEM majors

PIQL



Initial Exploration



Research Question

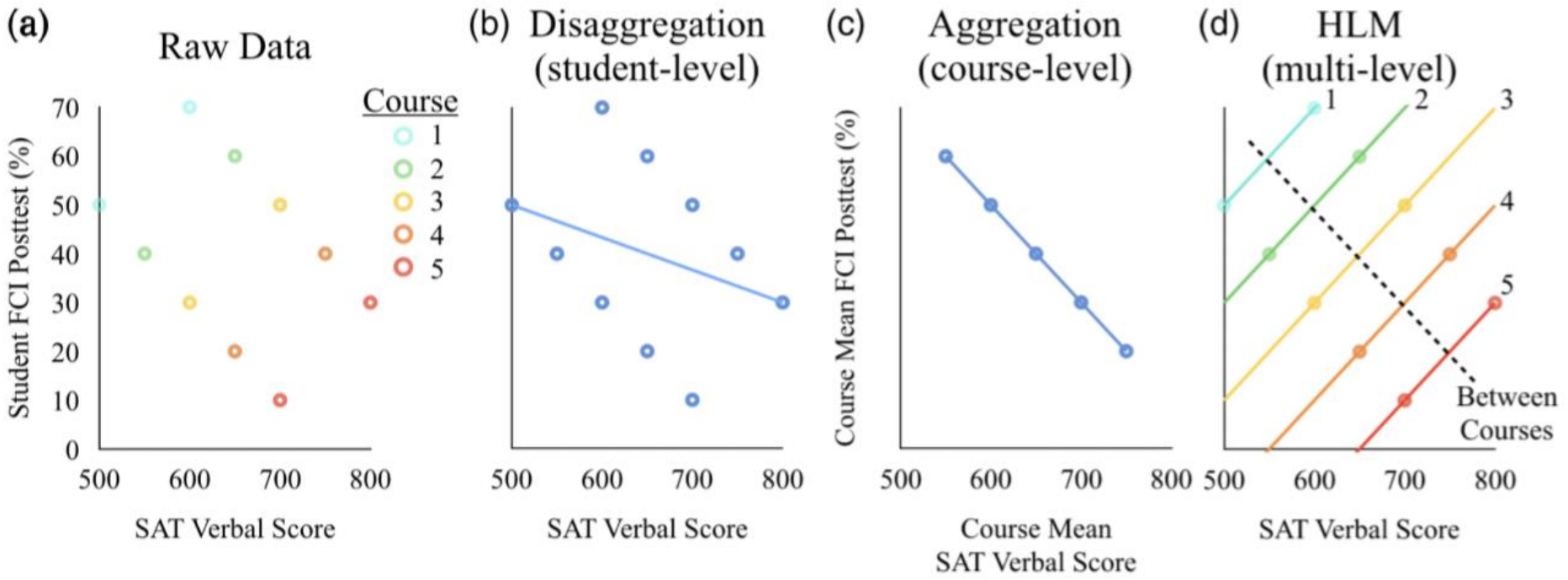
- Data from Spring quarter 2019, introductory physics classes at UW
- Collected as a pre-test, at the beginning of each course
- 121 – Mechanics
- 122 – Electromagnetism
- 123 – Waves
- **How do gender, course grade and SAT math score interact with PIQL score?**

Method: Hierarchical Linear Modeling

- Based on work of Van Dusen, Ben & Nissen, Jayson. (2019).
- Traditional method would be multiple linear regression (MLR)
- Hierarchical structure is not taken into account with normal regression
- Example structure:
  - Level 1: Student
  - Level 2: Course
  - Level 3: Institution
- HLM controls for unexpected differences between higher-level variables
- Assumption of independence not needed

Method: HLM

Student (Level 1)	Course (Level 2)	Student SAT verbal (Level 1)	FCI post-test (Level 1)
1	1	500	50
2	1	600	70
3	2	550	40
4	2	650	60
5	3	600	30
6	3	700	50
7	4	650	20
8	4	750	40
9	5	700	10
10	5	800	30



Adapted from Van Dusen and Nissen "Modernizing use of regression models in physics education research: A review of hierarchical linear modeling"

Method: Hierarchical Linear Modeling

Base Model

- Level 1: $score_{ij} = \beta_{0j} + r_{ij}$ (Student)
- Level 2: $\beta_{0j} = \gamma_{00} + u_{0j}$ (Class section)

Coefficient Factor Value

Final Model:

- Level 1: $score_{ij} = \beta_{0j} + \beta_{1j} * \boldsymbol{Course\ Grade_{ij}} + \beta_{2j} * \boldsymbol{SAT\ Math_{ij}} + r_{ij}$
- Level 2: $\beta_{0j} = \gamma_{00} + u_{0j}$; $\beta_{1j} = \gamma_{10}$; $\beta_{2j} = \gamma_{20}$

i – student

j – section

Results: HLM

Variables Added	% Lvl 1 (student) Variance Explained	% Lvl 2 (section) Variance Explained
None	0	0
Grade	26	7.5
SAT Math	20	11
Grade + SAT Math	31	14

Grade: Positive correlation
SAT Math: Positive correlation

Results: MLR

Percent Reduced Variance in each Course

Variables Added	% Variance Explained
None	0
Grade	24
SAT Math	19
Grade + SAT Math	30

Grade: Positive correlation
SAT Math: Positive correlation

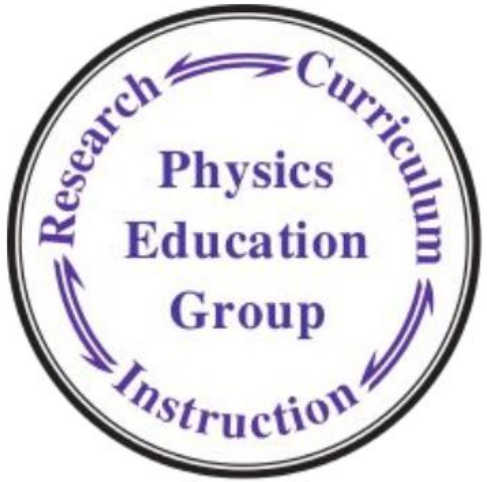
Results and Conclusions

- Course grade and SAT math score reduced the variance the most
- Course grade had a higher reduction of the variance
- Gender did not reduce the variance significantly
- PQL is potentially a predictor of course grade, before the course starts

Further Research

- Explore correlation between SAT math score and PIQL score
- Gather more data to increase strength of claims
- Look at ethnicity, demographic differences
- Look across institutions (community college, 4-year college, etc.)

PIQL



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