Developing a reasoning inventory for measuring physics quantitative literacy

Trevor I. Smith,[1] Suzanne White Brahmia,[2] Alexis Olsho,[2] Andrew Boudreaux,[3] Philip Eaton[4]

1 Rowan University
2 University of Washington
3 Western Washington University
4 Montana State University

Promoting quantitative literacy in physics

- Physics Quantitative Literacy (PQL): the ability to reason mathematically in the context of physics
- A goal of many introductory physics courses; development is often less than desired (Brahmia, 2017).
- Enhancing PQL development may:
  - improve students' knowledge of mathematics (Ellis, 2007; Thompson, 2010),
  - better prepare them for future demands to think mathematically (Caballero, et al., 2015), and
  - promote increased equity and inclusion in physics instruction (Brahmia and Boudreaux, 2017; Boaler, 2015).

Research Questions

- How does PQL develop throughout the introductory physics course sequence?
- How do students' understanding of physics content and mathematical reasoning skills interact to impact their PQL abilities?

Enter: the PIQL

- We are developing the Physics Inventory of Quantitative Literacy (PIQL): an assessment instrument for measuring PQL across the physics curriculum.
- 20 multiple-choice questions
  - 11 Single response
  - 9 Multiple response (3 have more than one correct response)
- Given as a pretest in three introductory physics courses
  - Phys121, Mechanics (N = 424)
  - Phys122, Electricity & Magnetism (N = 405)
  - Phys123, Thermodynamics/Waves (N = 329)
- We focus on three constructs:
  - proportional reasoning(Arons, 1983; Boudreaux, et al., 2015)
  - reasoning with signed quantities (Bajracharya, et al., 2012; Brahmia and Boudreaux, 2016; Brahmia, 2017; Hayes and Wittmann, 2010; Vlassis, 2004)
  - co-variational reasoning (Carlson, et al., 2010)
- Typical test statistics (such as Cronbach's α) may not be relevant because we are trying to measure multiple constructs, want some challenging items that would demonstrate mastery, and don't want students and instructors to be discouraged by extremely low scores (Adams and Wieman, 2010).

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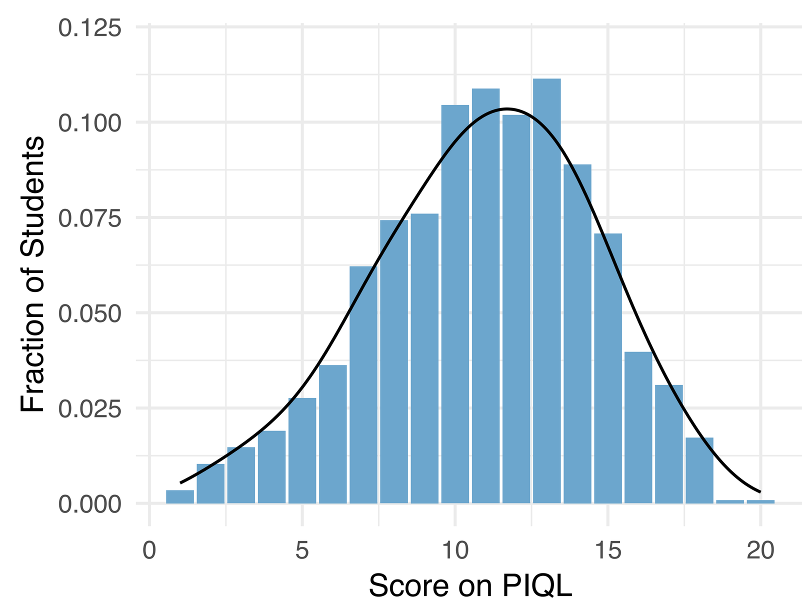
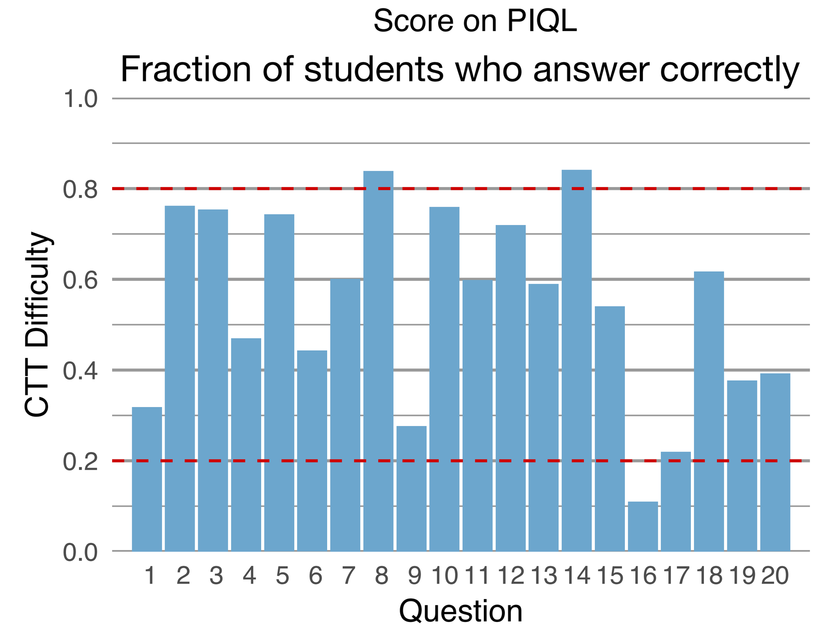
DUE-1832836
DUE-1833050

Score Distribution

- Scores range from 1 to 20 correct
- Small increases from course to course
- Broad range of item difficulty values

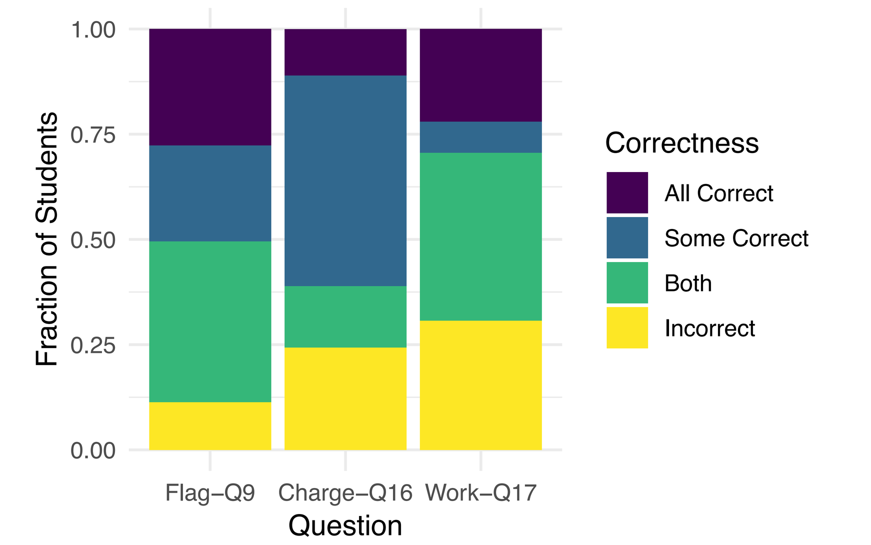
	Mean	Median	St. Dev.	Skewness	Kurtosis
Overall	10.9	11	3.55	-0.30	-0.29
Phys121	10.3	11	3.36	-0.21	-0.33
Phys122	11.0	11	3.70	-0.32	-0.34
Phys123	11.7	12	3.44	-0.47	-0.03

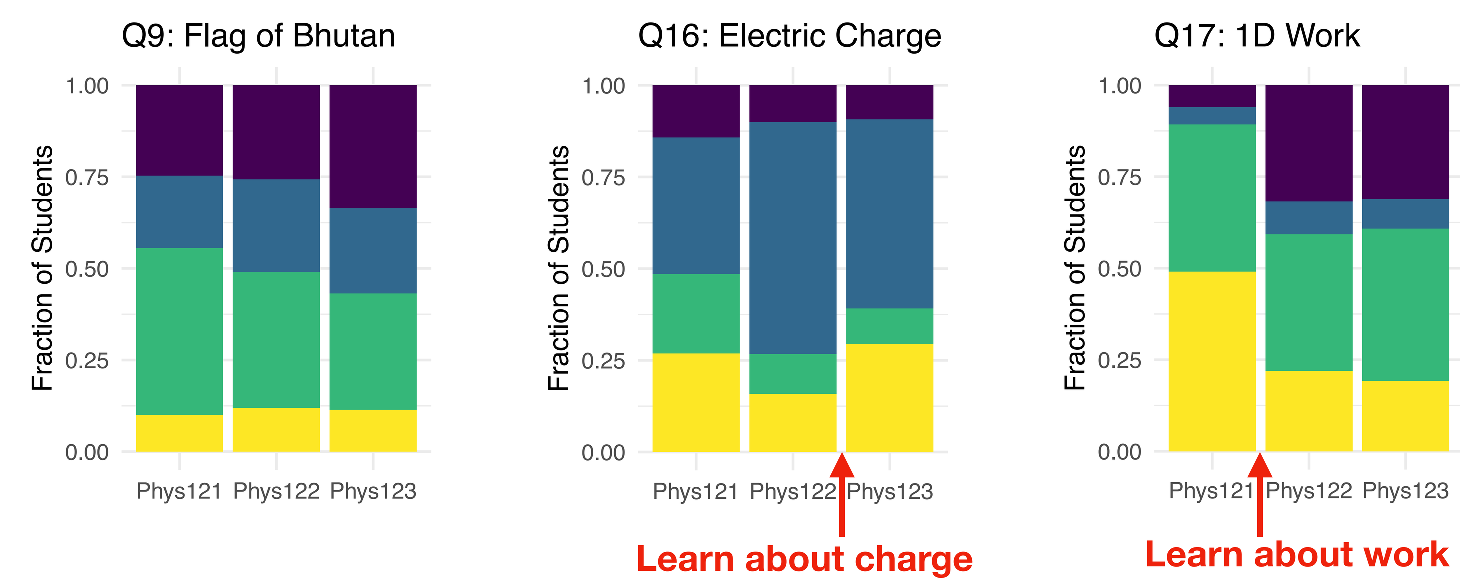




Multiple-Choice Multiple-Response

- Most students choose at least one correct response
- Four-level scoring scheme
  - All Correct
  - Some Correct (Choosing at least one correct response, but no incorrect responses)
  - Both (Choosing at least one correct and one incorrect response)
  - Incorrect
- Progression over time varies by question

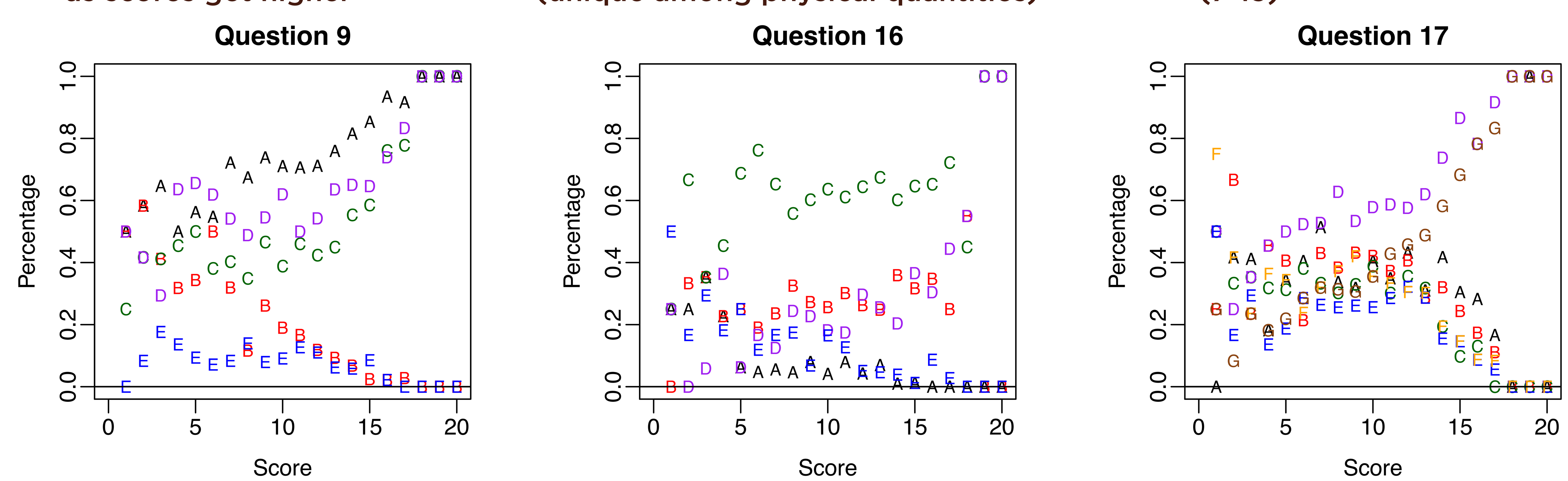




Which Responses do Students Choose?

- Item Response Curves (IRCs) Plot the probability of a student choosing a particular response, given her/his overall score on the PIQL
- Useful for seeing which of the answers students choose (particularly for MCMR questions)
- Only 1 student scored 19, only 1 student scored 20

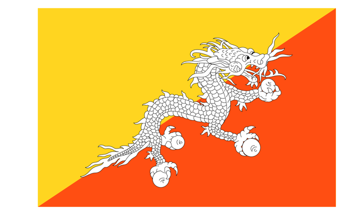
- Q9: Flag of Bhutan
  - Choosing Perimeter (A) is more likely than choosing Diagonal (D), which is more likely than choosing the Curve (C)
  - Incorrectly choosing Area (B) gradually decreases as scores get higher
- Q16: Electric Charge
  - Many students correctly indicate that the size of the net charge implies magnitude (C), regardless of score
  - A common distractor is that negative net charge is less than positive net charge (B); this is inconsistent with the negative sign indicating type of charge (unique among physical quantities)
- Q17: 1D Work
  - More likely to answer correctly about the dot product (D: $W = \vec{F} \cdot \vec{\Delta s}$) than physical implications (G: $W = \Delta E$)
  - All distractors common for mid-range scores (7-13)



Example Questions

Important: Some of the questions on this page may have more than one correct answer. If you see the prompt *"Choose all that apply"*, select ALL ANSWERS you believe are correct.

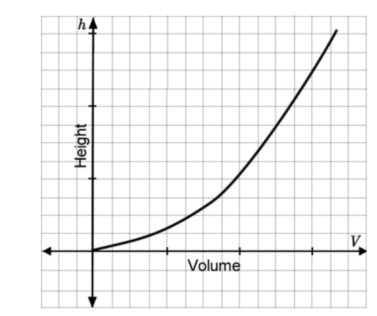
9. Shown at right is a picture of a small flag of the Kingdom of Bhutan, which has a dragon along its diagonal. A second version of the flag, not shown, is 1.5 times taller than the smaller flag and is also 1.5 times wider. Which of the quantities below are larger by a factor of 1.5 for the larger flag compared to the smaller flag? ***Choose all that apply.***

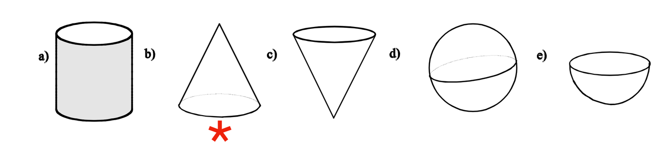


* a. The distance around the edge of the flag.
  b. The amount of cloth needed to make the flag.
* c. The length of the curve forming the dragon's backbone.
* d. The diagonal of the flag.
  e. None of these quantities are larger by a factor of 1.5 for the larger flag compared to the smaller flag.

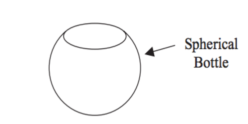
10. Jogger A is slower than jogger B (0.6 times the speed of jogger B) but runs for a longer time (1.5 times the amount of time that jogger B runs). How does the distance traveled by A compare to the distance traveled by B? Select the answer with the best reasoning:
  a. The distance traveled by A is greater than B because A runs for more time.
  b. The distance traveled by B is greater than A because B runs faster.
  c. They both run the same distance because although A runs for more time, B runs faster and it balances out.
  d. The distance traveled by A is greater because although B runs faster, A runs long enough that he passes B and keeps going once B has stopped.
* e. The distance traveled by B is greater because although A runs for more time, A doesn't run long enough to travel as much distance as B traveled before she stopped.

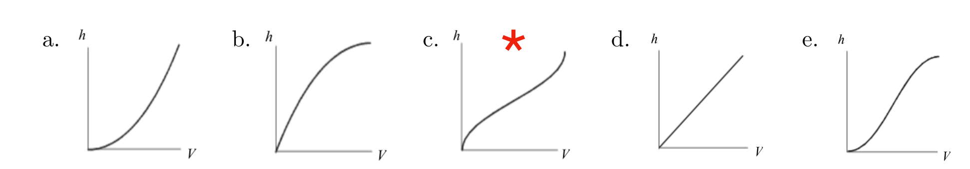
11. The graph at right represents the height of water as a function of volume as water is poured into a container. Which of the containers shown below could be represented by this graph? ***Choose all that apply.***





12. Assume that water is poured into a spherical bottle at a constant rate. Which of the following graphs best represents the height of the water, h, in the spherical bottle as a function of the amount of water in the bottle, V?





16. A student has two electrically neutral spheres, A and B. Initially, sphere A has exactly the same number of protons and electrons as sphere B. The student touches the spheres to each other. After the spheres touch, the charge on sphere A is measured to be $q_A = -5\ \mu C$, and the charge on sphere B is $q_B = +5\ \mu C$.
Which of the following statements best describe the charges on the spheres after the spheres touch each other? Select the statement(s) that **must be true.** ***Choose all that apply.***
  a. The net charge on sphere A is greater than the net charge on sphere B.
  b. The net charge on sphere A is less than the net charge on sphere B.
* c. The net charge on sphere A is neither greater than nor less than the net charge on sphere B.
* d. The number of charged particles in sphere A is greater than that in sphere B.
  e. The number of charged particles in sphere A is less than that in sphere B.

17. 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, $W = \vec{F} \cdot \vec{\Delta s}$.
Consider the following statements about this situation. Select the statement(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.

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