Developing a reasoning inventory for measuring physics quantitative literacy

Trevor I. Smith,1 Suzanne White Brahmia,2 Alexis Olsho,2 Andrew Boudreaux,3 Philip Eaton4

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).

Score Distribution

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

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Median</th>
<th>St. Dev.</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>10.9</td>
<td>11</td>
<td>3.55</td>
<td>-0.30</td>
<td>-0.29</td>
</tr>
<tr>
<td>Phys121</td>
<td>10.3</td>
<td>11</td>
<td>3.36</td>
<td>-0.21</td>
<td>-0.33</td>
</tr>
<tr>
<td>Phys122</td>
<td>11.0</td>
<td>11.1</td>
<td>3.70</td>
<td>-0.32</td>
<td>-0.34</td>
</tr>
<tr>
<td>Phys123</td>
<td>11.7</td>
<td>12</td>
<td>3.44</td>
<td>-0.47</td>
<td>-0.03</td>
</tr>
</tbody>
</table>

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

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: \( \vec{W} = \vec{F} \cdot \vec{S} \)) than physical implications (G: \( \vec{W} = \Delta \vec{E} \))
- All distractors common for mid-range scores (7-13)

References