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The Development of a Valid and Reliable Biogeochemistry Concept Inventory

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Abstract for DBER Group Discussion on 2014-11-06

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Title:
The Development of a Valid and Reliable Biogeochemistry Concept Inventory

Abstract:
Concept inventories are a commonly used tool to measure conceptual understanding. To date, concept inventories have been published for geology, chemistry, and biology, but no instrument has been designed to measure conceptual understanding at the intersection of those fields. To fill that gap, we constructed a 32-item biogeochemistry concept inventory (BGC-CI). Item response theory analysis, using the Rasch model, shows the BGC-CI is a reliable and valid tool to measure the biogeochemistry knowledge of science majors. Because biogeochemistry is an interdisciplinary field, we were concerned about the unidimensionality of the instrument. However, our analysis showed the BGC-CI to be acceptably unidimensional among science majors. The subject matter included on the BGC-CI is applicable to climate science, oceanography, and environmental science, among other fields. This instrument will allow researchers and teachers to readily quantify learning outcomes in these fields and others that overlap with biogeochemistry.

Identifying and Assessing Biogeochemistry Misconceptions

What Do Undergraduates Know? [about biogeochemistry]

- Divided into two studies:
    - Interviews to identify misconceptions
    - Validation of a misconceptions survey
- Studies share common foundation
    - Concept list & preliminary interviews

Study Populations

Task	Population(s)
Content Expert Survey	18 professors in biogeochemistry or related field from a range of institutions
Interviews	8 undergraduate science majors
Concept Survey	251 undergraduates "*Intro*": non-majors from 100-level geology courses "*Advanced*": science majors from a 300-level chemistry course
Additional Interviews	32 undergraduates; mainly biology / chemistry / geology majors; 3 non-science majors

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BGC Misconceptions

Cluster Description		Instances (n = 32)
Climate Change	Climate Change Drivers	19
	Greenhouse Effect Mechanisms	8
	Climate Change History	6
Oxygen	O_2	23
	Fish Respiration	5
	Source of O	19
	Anaerobic Life	6
The pH of Natural Waters	Ocean pH	5
	Rainwater pH	3
	CO	5
Other	Soil	7
	Overstating Human Impacts	6
	Stability and Life	7

Oxygen Misconceptions

Incorrect	Correct	% Incorrect Intro / Advanced
There is no O bottom of the ocean	Global ocean circulation supplies the deep ocean with O	85% / 68% unaware of ocean circulation
Fish respire using the oxygen from the H molecule	The oxygen in O are chemically different	75% / 44%
It would be possible to have significant atmospheric O Earth without life	Inorganic processes produce very small amounts of O	71% / 59%

pH Misconceptions

Incorrect	Correct	% Incorrect Intro / Advanced
Ocean water has an acidic pH	Ocean water has a basic pH	70% / 42%
Rain water would be neutral pH without humans	Rain water would have an acidic pH even without humans	66% / 60%
CO ocean pH	CO on both ocean and rain water	48% / 22%

BGC Concepts Require Interdisciplinary Knowledge

- These concepts all connect multiple disciplines
- Respondents with some discipline specific knowledge can have misconceptions in the interdisciplinary gaps

Concept Inventories (CI)

- Quick assessment of conceptual understanding
    - Pre-, Post-Course assessment
    - Grounded in student thinking
    - Exist for Physics, Geology, Biology, Chemistry, Astronomy, among others
    - My work is among the first interdisciplinary CI

Instrument Evaluation: Validity & Reliability

- Validity
  - What are scores on a test *supposed* to represent?
    - How do you know the scores represent that?
- Reliability
  - Are the scores reproducible?

Rasch Model

- Non-standard use of the word "model"
- Posits ideal item–response relationship
  - Unidimensionality
  - Uniform item discrimination
- Rejects items that do not fit model
- That this relationship is correct is an assumption of my work

Rasch Model

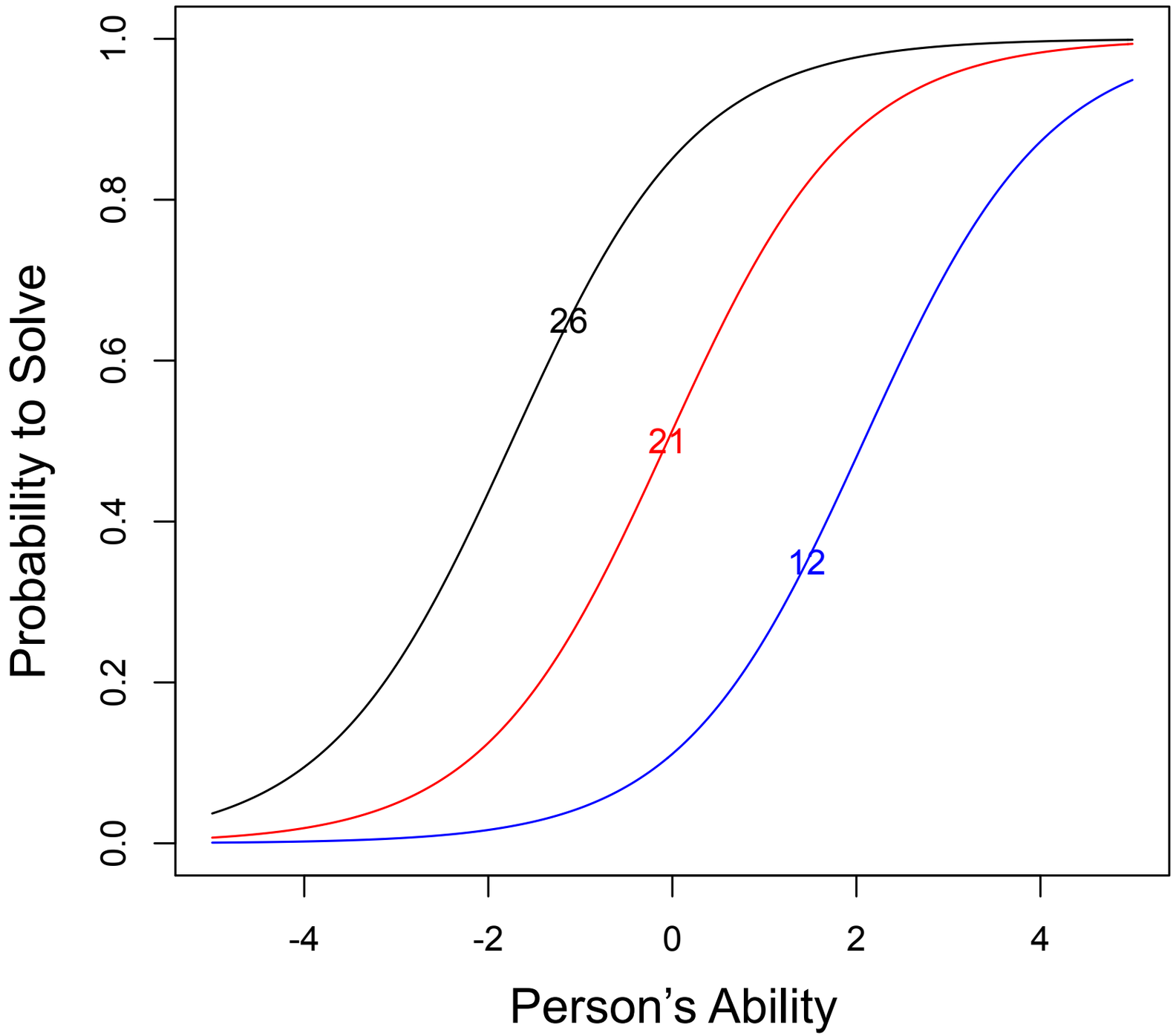
- Georg Rasch (1960)
- Probability that a random person of proficiency θ will correctly answer an item of difficulty b_i

$$\mathrm{P}_i(\theta) = \frac{\mathrm{e}^{(\theta - b_i)}}{1+\mathrm{e}^{(\theta - b_i)}}$$

- Item difficulties and person proficiencies are solved for simultaneously
- Once an instrument is shown to fit the Rasch model, it can be assumed to have a certain set of measurement properties

Rasch Model

$$\mathrm{P}_i(\theta) = \frac{\mathrm{e}^{(\theta - b_i)}}{1+\mathrm{e}^{(\theta - b_i)}}$$



Descriptive Rasch Statistics

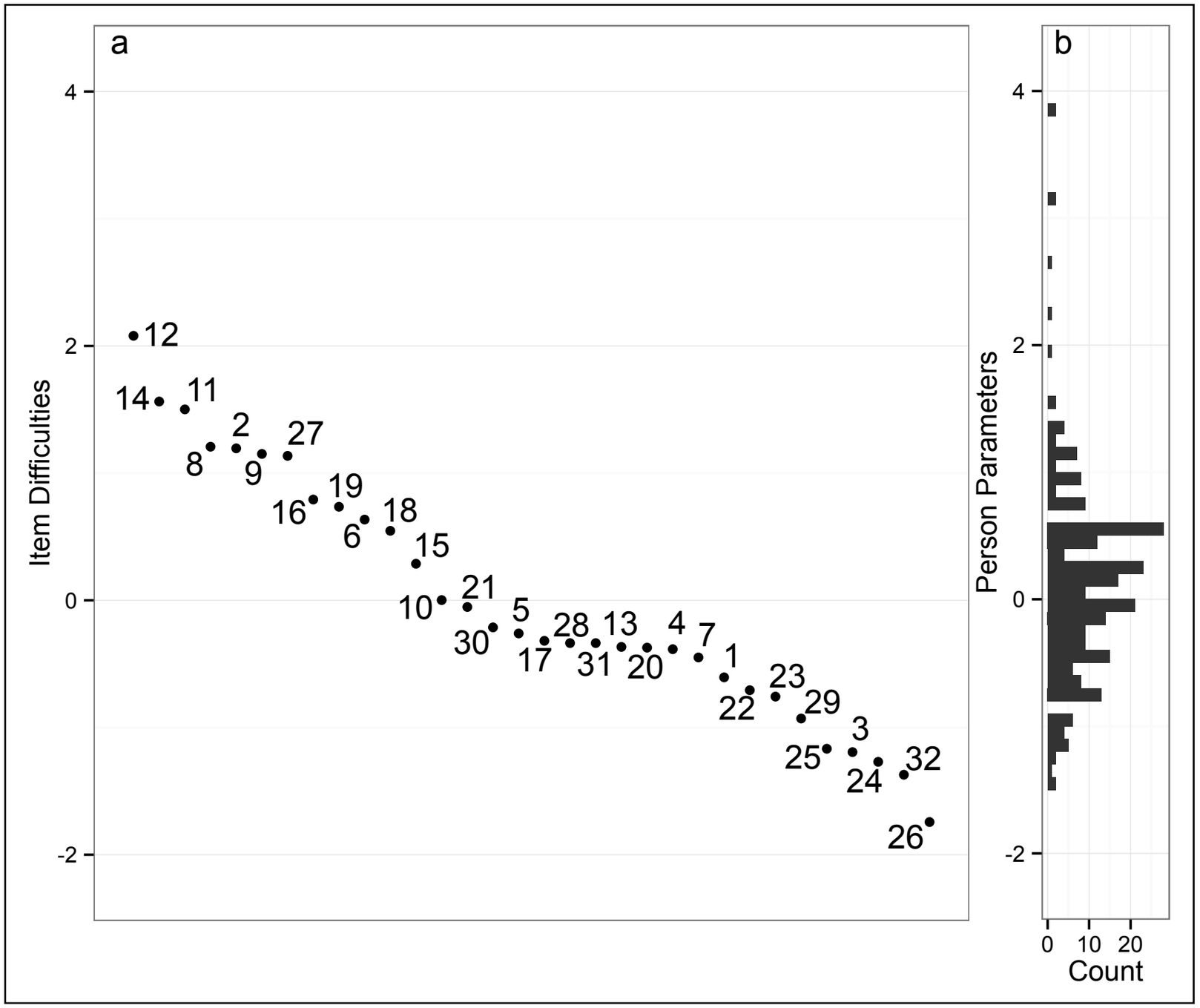
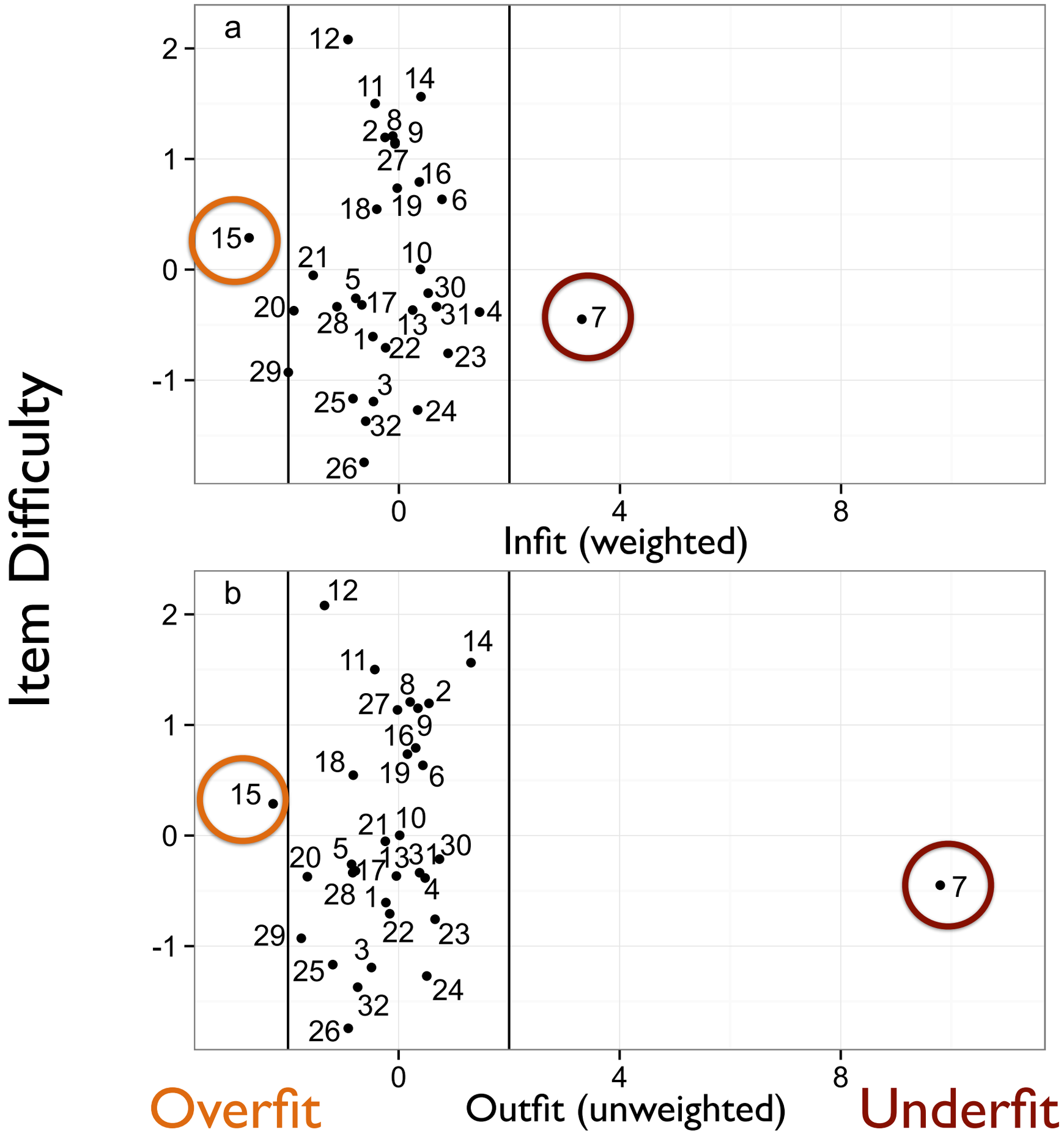
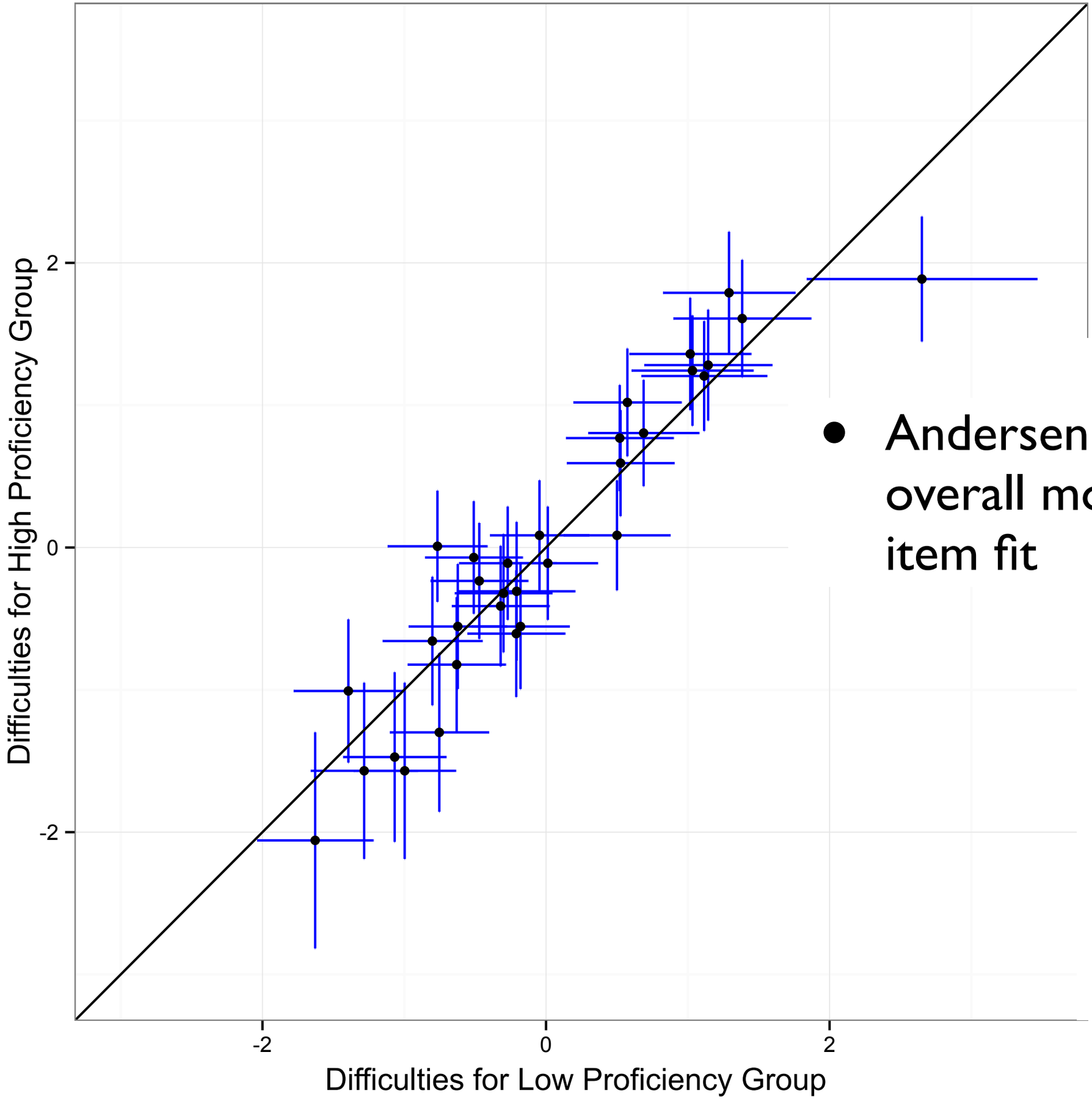


Figure 2: Item difficulties and person parameters (abilities)

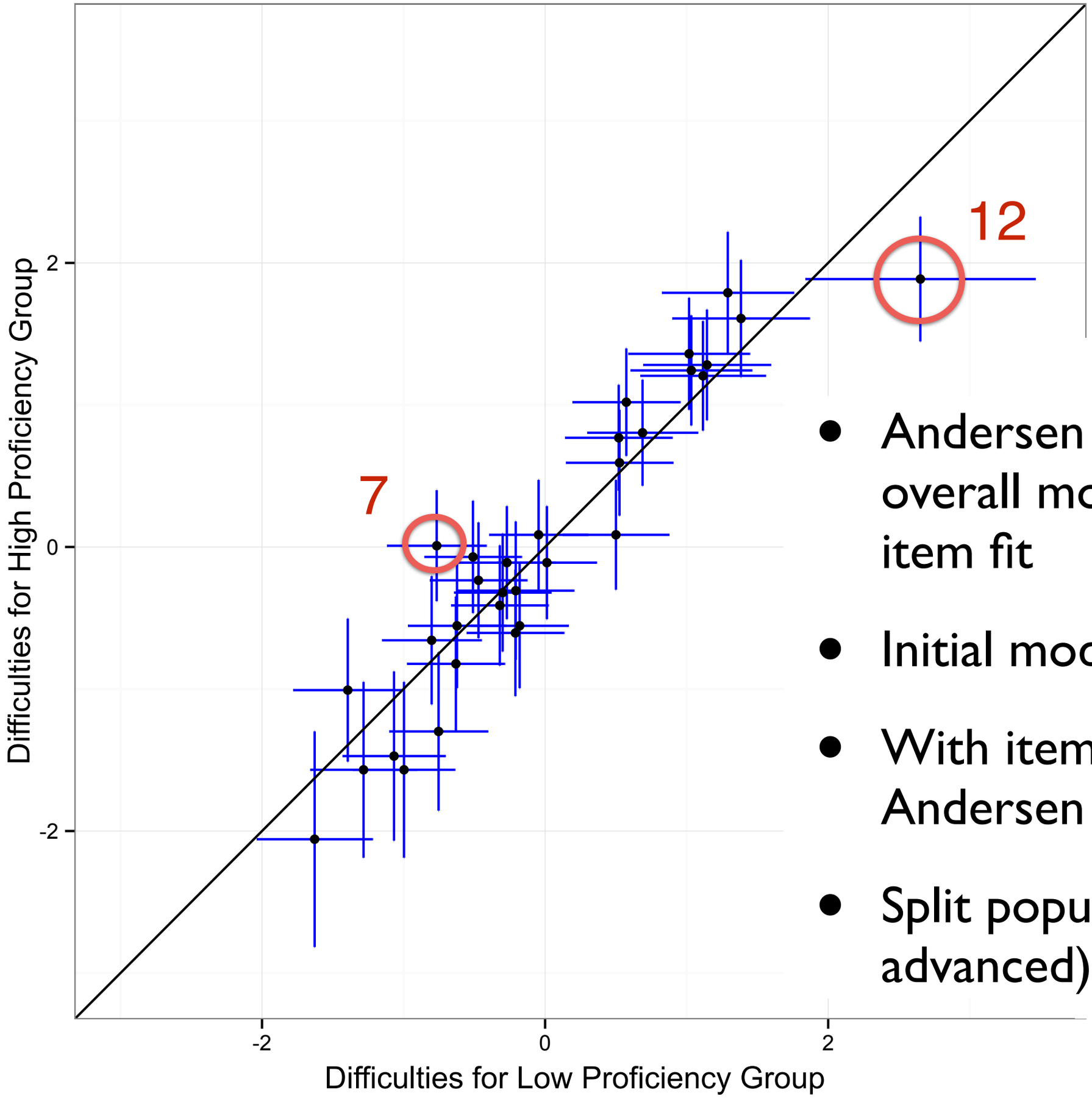
Rasch Model Evaluation

- Model fit is evaluated item by item and overall
- Item fit
    - Outfit & Infit
- Overall fit
    - Andersen likelihood ratio test
    - NOHARM
    - Principal component analysis


a
b
Item Difficulty
Infit (weighted)
Outfit (unweighted)
Overfit
Underfit
2
1
0
-1
0
4
8
12
11
14
8
2
9
27
16
18
19
6
15
21
10
5
30
20
17
31
4
28
13
1
22
23
29
3
25
24
32
26
7



- Andersen test measures overall model fit as well as item fit



- Andersen test measures overall model fit as well as item fit
- Initial model fit is acceptable
- With item 7 removed, fails Andersen test
- Split populations (intro/ advanced)

Dimensionality

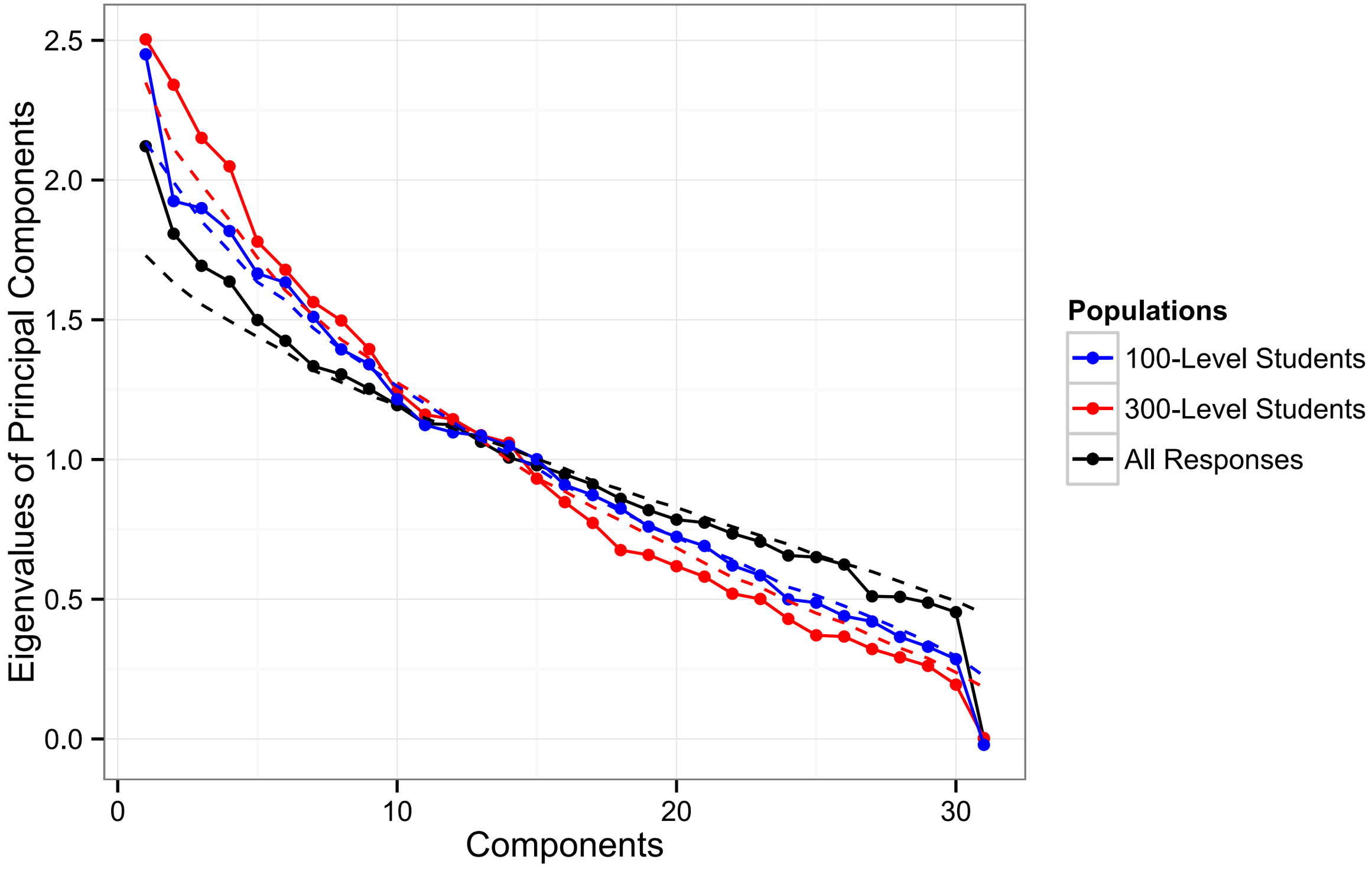
- How many traits does the instrument measure?
- Assessed in two ways: NOHARM test and principal component analysis
- No firm rules; judgement call

Tests of Overall Model Fit

Version	Group	Andersen LR Test	X		Tanaka Goodness-of-Fit Index		RMS	
			1 Dim.	2 Dim.	1 Dim.	2 Dim.	1 Dim.	2 Dim.
Full	All (n = 251)	Accept (*p = 0.11*)	Reject (*p < 0.001*)	Accept (*p = 0.87*)	Accept (GoF = 0.90)	Accept (GoF = 0.92)	0.014	0.012
Revised	All (n = 251)	Reject (*p = 0.02*)	Reject (*p < 0.001*)	Accept (*p = 0.77*)	Accept (GoF = 0.90)	Accept (GoF = 0.93)	0.014	0.012
Revised	100-level (n = 115)	Accept (*p = 0.86*)	Accept (*p = 0.99*)	Accept (*p = 0.99*)	Reject (GoF = 0.83)	Reject (GoF = 0.86)	0.018	0.016
Revised	300-level (n = 93)	Accept (*p = 0.50*)	Accept (*p = 0.79*)	Accept (*p = 0.99*)	Reject (GoF = 0.81)	Reject (GoF = 0.84)	0.020	0.018

[a]Excludes item 7

PCA of Residuals



Summary of Validity Argument

- Good item fit (with one exception)
- Borderline overall model fit for total population
- Good model fit for the 300-level population
- BGC-CI may be too difficult for 100-level population OR a more evenly distributed population may be needed to achieve good overall model fit

Instrument Revisions

Item	Action	Rationale
7	Remove	Very poor fit. Topic (enzymes) is substantially different from other items.

7. What role do enzymes play in helping living things obtain energy?

a. Enzymes make certain chemical reactions thermodynamically favorable that would not be favorable otherwise.
b. Enzymes make certain chemical reactions occur faster than they would otherwise.
c. Enzymes do not play a role in the process of obtaining energy for living things.

Instrument Revisions

Item	Action	Rationale
12	Revise	Very difficult, moderately poor fit. Item is complex and could be split in two.

12. The Earth has a protective layer known as the ozone later that keeps out ultraviolet radiation. Which of the following is also true about that layer?

a. Pollution has made it thicker, and that is making the planet hotter.
b. Pollution has made it thinner, and that is making the planet hotter.
c. Pollution has made it thicker, but there is no connection with the Earth's temperature.
d. Pollution has made it thinner, but there is no connection with the Earth's temperature.

Instrument Revisions

Item	Action	Rationale
14, 15, 29	Revise	Moderately poor fit. Correct answer to each is "all of the above" which can be a give away.

15. How do plants affect the weathering of rocks?

a. Plants stabilize rocks, thus reducing weathering.
b. Over time, plant growth can break up rocks through physical weathering, but plants do not affect chemical weathering.
c. Plants release chemicals that cause chemical weathering of rocks (e.g., dissolution), but plants do not contribute to physical weathering.
d. Plants cause both physical and chemical weathering.
e. Plants do not affect the weathering of rocks.