What every science educator should know about psychometrics

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HHMI education group meeting 2/28/2013

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

RELATE
Research in Learning, Assessing and Tutoring Effectively

Psychometrics

measurement of psychological (psychosocial) phenomena

informed by: statistics | psychology | psychophysics
cognitive science | computer science

includes:

- educational measurement
  - math ability
  - reading ability
- personality testing
- intelligence testing

Testing is a big part of the story

Scale development requires anticipating the evidence

For the science educator,

psychometrics is not the answer, per se

it *may provide insight in framing the question*

"Advanced technologies and statistical methods aren't sufficient. One must design a complex assessment from the very start around the inferences one wants to make, the observations one needs to ground them, the situations that will evoke those observations, and the chain of reasoning that connects them."

Mislevy, Steinberg and Almond (channeling Messick)

maybe this is you

Weighting scheme		
Task	Code	Weight
3 Exams	E	45%
Final Exam	FE	25%
Problem Sets	PS	10%
Reading Questions	RQ	5%
Concept Questions	CQ	5%
In Class Work: Friday Problem Solving and Experiments	IC	10%

http://web.mit.edu/8.01t/www/coursedocs/overview/grades.htm

or maybe this is you

Landysh Zaripova, Russian Prof., Forces Students To Endure 23-Hour Oral Physics Exam

The Huffington Post | By Alyssa Creamer
Posted: 07/06/2012 2:58 pm Updated: 07/06/2012 3:01 pm

Around 15 Russian students may have now seen the chaos theory at work after sticking out (and failing!) a 23-hour nuclear physics exam proctored by their allegedly drunk and belligerent professor.

According to RIA Novost, a Russian media outlet, Kazan University students said that their physics professor, Landysh Zaripova, "stank of alcohol" and forced the students to listen to her prattle on about her business and wardrobe during her long-winded oral examination.

She refused to allow students to leave the room for any reason - not even to go to the bathroom or grab some food. The exam began at 10 a.m. on June 26 and lasted until 9 a.m. the following morning.

"Towards the end, everyone was just sitting there, totally exhausted," one student said, according to RIA Novost. "The lecturer would go into another room, drink, come back and start telling us about her business."

In response to the ordeal, the students wrote a letter to the University administration asking for Zaripova to be suspended.

Zaripova denied she was drunk, instead suggesting that the students were seeking vengeance on her for failing them. In order to pass exams in Russia, students must receive satisfactory clearance from their professor based on their oral answers.

Albert Aganov, Kazan University's physics department head, did not believe the professor was intoxicated, according to RIA Novost, saying, "I would have fired her immediately, if I had seen her drunk." He also told Russian media that the test's length was "not unusual."

However, Aganov, also told the Daily Mail that even if Zaripova were to be found to have proctored the exam while under the influence, she could not be terminated until her 5-year contract was up.

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http://www.huffingtonpost.com/2012/07/06/landysh-zaripova-russian-_n_1654529.html

either way, or somewhere in between, this is definitely you

(extremely perceptive, highly evolved)

Face to face, at least, you know many different ways to evaluate a peer or student.

e.g. Bloom's 2-sigma effect for expert tutors

So why don't we all just do the best we can?

Because we worry about *fairness and quality*

in fact, this is a very old concern...

מאזני מרמה תועבת יהוה ואבן שלמה רצונו:

A false balance is an abomination to the LORD, but
a just weight is his delight.

Proverbs

Penny Tour

Measurement & Constructs (or Latent Variables)

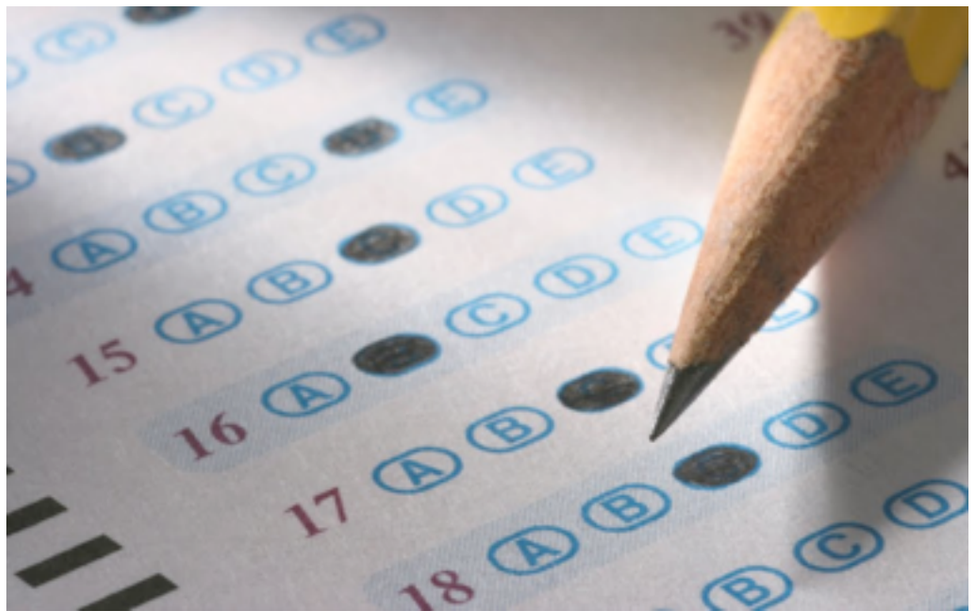
Reliability & Validity (psychometric quality)

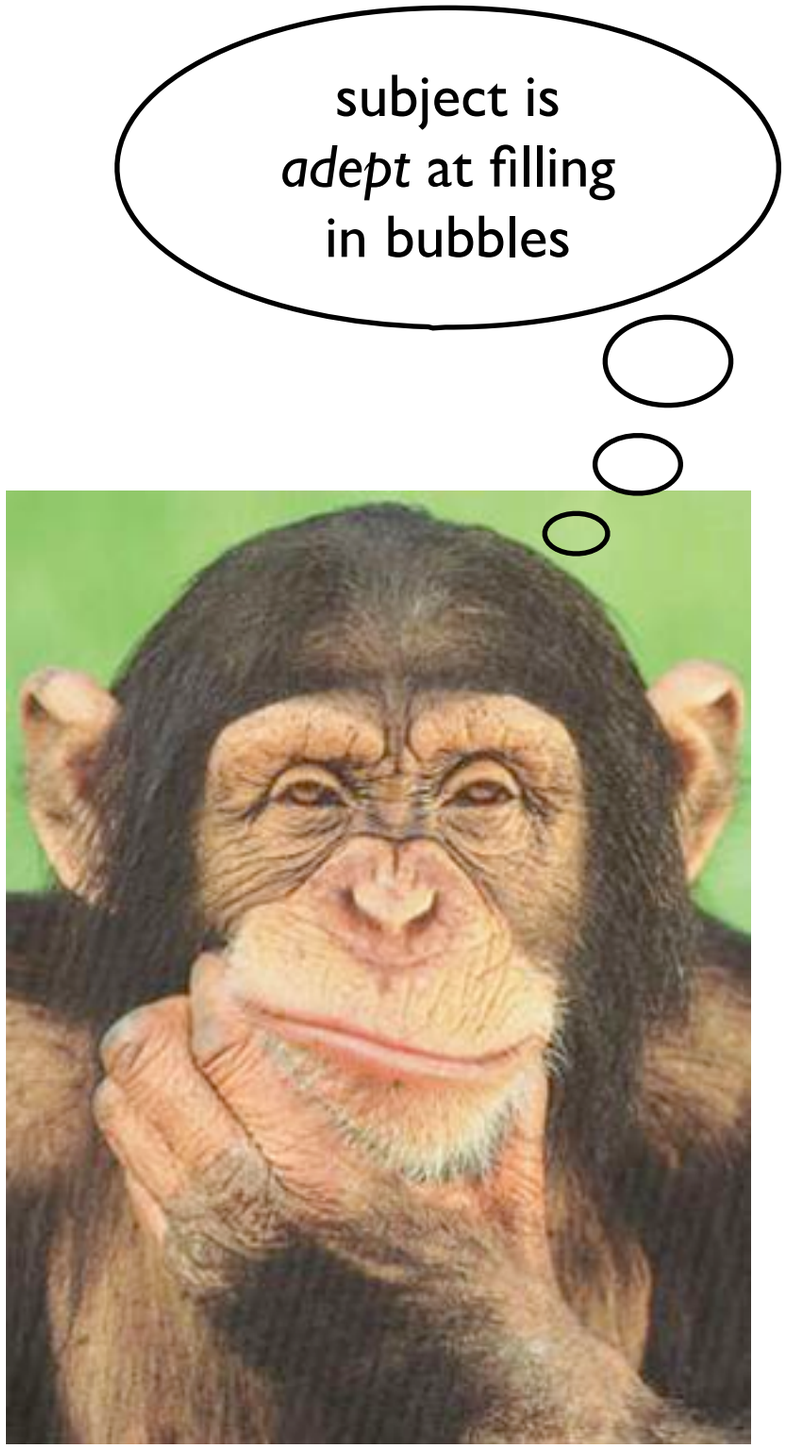
Graphs (aka paths)

Item Response Theory (with some examples)

Cronbach: a construct is some postulated attribute of people, assumed to be reflected in test performance...[T]he attribute about which we make statements in interpreting a test is a construct.

depression
extraversion
masculinity
scholastic aptitude
chemistry achievement
critical thinking
(new constructs are born all the time)



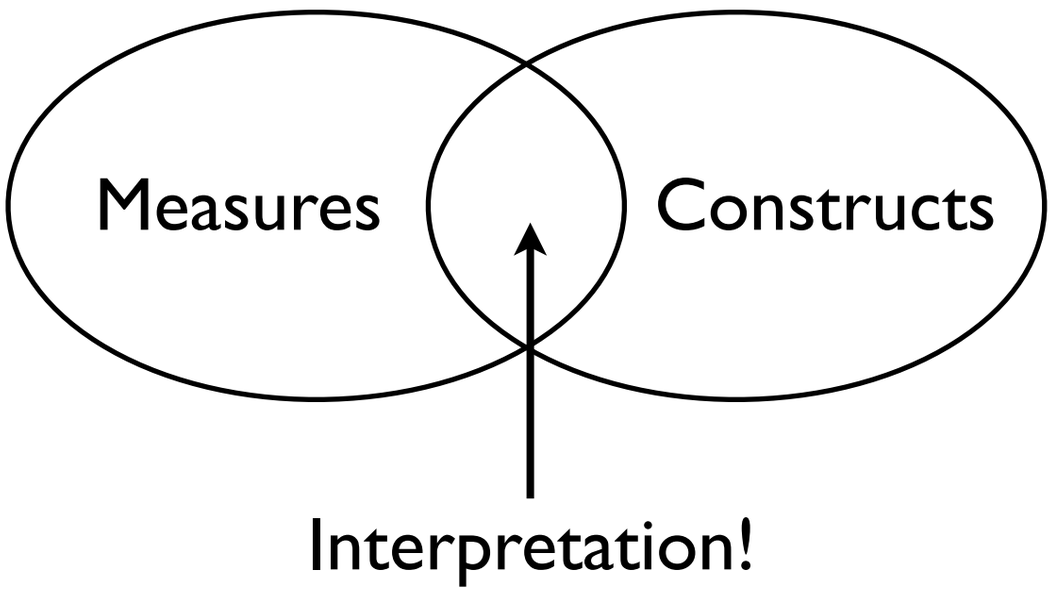


Percy Bridgman, Operation(al)ism
(*Logic of Modern Physics*, 1927)

"the concept is synonymous with a corresponding set of operations"

"the space of astronomy is not a physical space of meter sticks, but is a space of light waves"

http://www.youtube.com/user/minutephysics



Samuel Messick (1995)

"In construct validation the test score is not equated with the construct it attempts to tap, nor is it considered to define the construct, as in strict operationism (Cronbach & Meehl, 1955). Rather, the measure is viewed as just one of an extensible set of indicators of the construct. Convergent empirical relationships reflecting communality among such indicators are taken to imply the operation of the construct to the degree that discriminant evidence discounts the intrusion of alternative constructs as plausible rival hypotheses.

SCIENCE

Vol. 103, No. 2684 **Friday, June 7, 1946**

On the Theory of Scales of Measurement

S. S. Stevens

Director, Psycho-Acoustic Laboratory, Harvard University

FOR SEVEN YEARS A COMMITTEE of the British Association for the Advancement of Science debated the problem of measurement. Appointed in 1932 to represent Section A (Mathematical and Physical Sciences) and Section J (Psychology), the committee was instructed to consider and report upon the possibility of "quantitative estimates of sensory events"—meaning simply: Is it possible to measure human sensation? Deliberation led only to disagreement, mainly about what is meant by the term measurement. An interim report in 1938 found one member complaining that his colleagues "came out by that same door as they went in," and in order to have another try at agreement, the committee begged to be continued for another year.

For its final report (1940) the committee chose a

by the formal (mathematical) properties of the scales. Furthermore—and this is of great concern to several of the sciences—the statistical manipulations that can legitimately be applied to empirical data depend upon the type of scale against which the data are ordered.

A Classification of Scales of Measurement

Paraphrasing N. R. Campbell (Final Report, p. 340), we may say that measurement, in the broadest sense, is defined as the assignment of numerals to objects or events according to rules. The fact that numerals can be assigned under different rules leads to different kinds of scales and different kinds of measurement. The problem then becomes that of making explicit (a) the various rules for the assign-

ment of numerals, (b) the mathematical properties

Stanley Smith Stevens (*Science*, 1946):
"[Paraphrasing N. R. Campbell] we may say that measurement, in the broadest sense, is defined as the assignment of numerals to objects and events according to rules."

deprecated by Otis Duncan (1984) as incomplete:
"playing the piano is striking the keys of the instrument according to some pattern"

SS promotes theory of scale types

- nominal (classification)
- ordinal (e.g. IQ)
- interval (e.g. time)
- ratio (e.g. mass)

← science lives here, but few (if any) educational measurements do

Reliability

(i. quantitative; ii. necessary but not sufficient for validity)

inter-rater reliability

e.g. Cohen's kappa

how much better than chance

can also use for prediction models

test-retest reliability

different forms reliability

not that relevant for science educators

internal consistency, e.g. split-half

e.g. Cronbach's alpha is a number in [0,1], values closer to 1 are better and > 0.7 is a reasonable criterion

alpha is *not* a homogeneity or unidimensionality parameter (e.g. it gets larger as test length is increased; moreover, it is possible to demonstrate using a heterogeneous test of m dimensions that alpha is not sensitive to m directly)

Eric Mazur [FCI]: "How should I answer these questions—according to what you taught me, or how I usually think about these things?"

Validity

or, what is it all about?

validitation is about interpretation or meaning of scores,
it is not a measure of tests in and of themselves

criterion validity
- concurrent validity
- predictive validity

construct validity ⇢ alternately one unified concept with:
content, substantive, structural, generalizability,
external, and consequential aspects

content validity

Cronbach & Meehl, 1955

Messick, 1995

an example, not exhaustive

Construct invalidity can come from:

- construct underrepresentation (too narrow)
- construct-irrelevant variance (too broad)
  - construct-irrelevant difficulty (e.g. reading comprehension)
  - construct-irrelevant easiness (e.g. alternative solution)

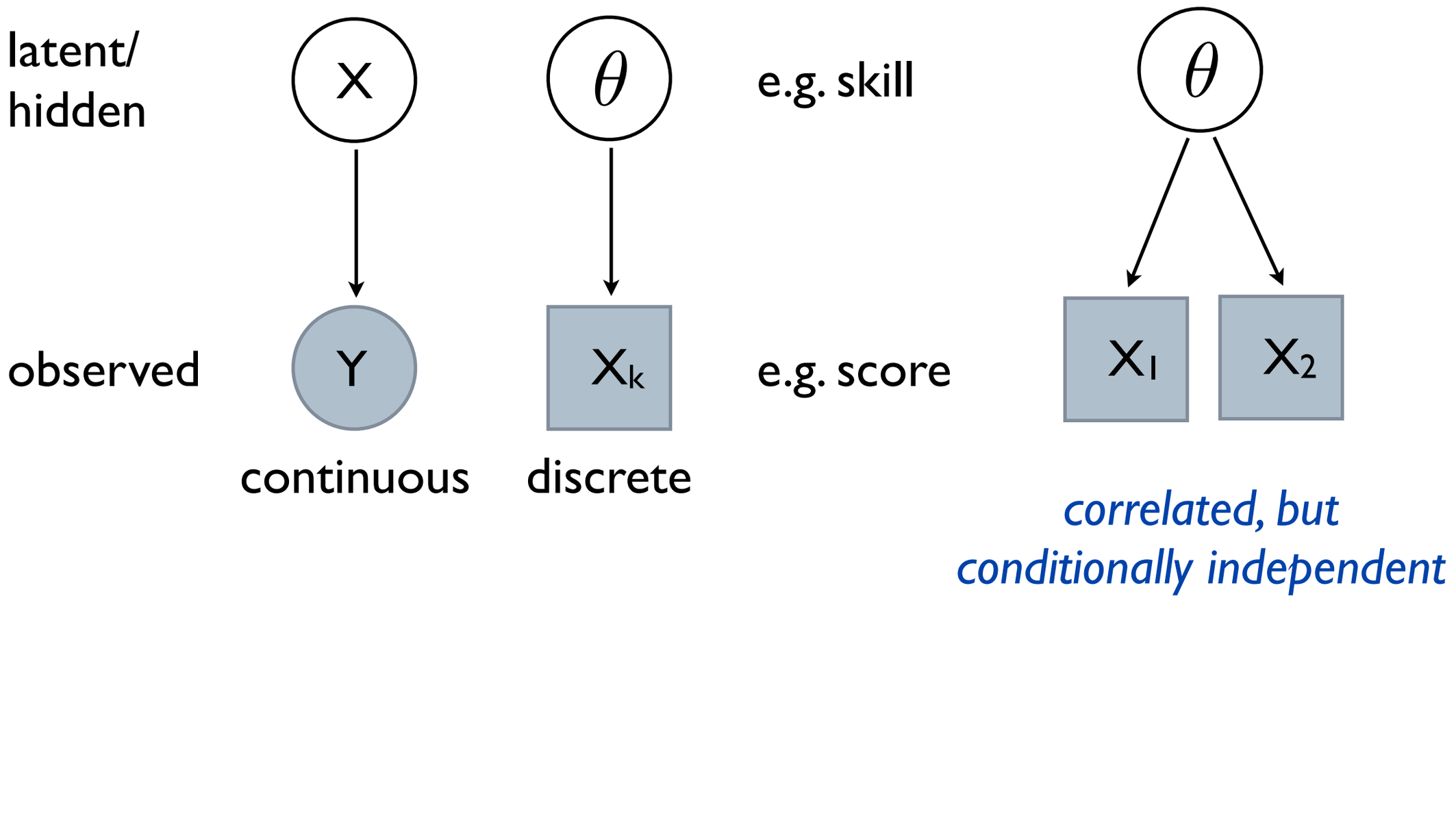
Criterion validity

Differential Item Functioning
(group bias)

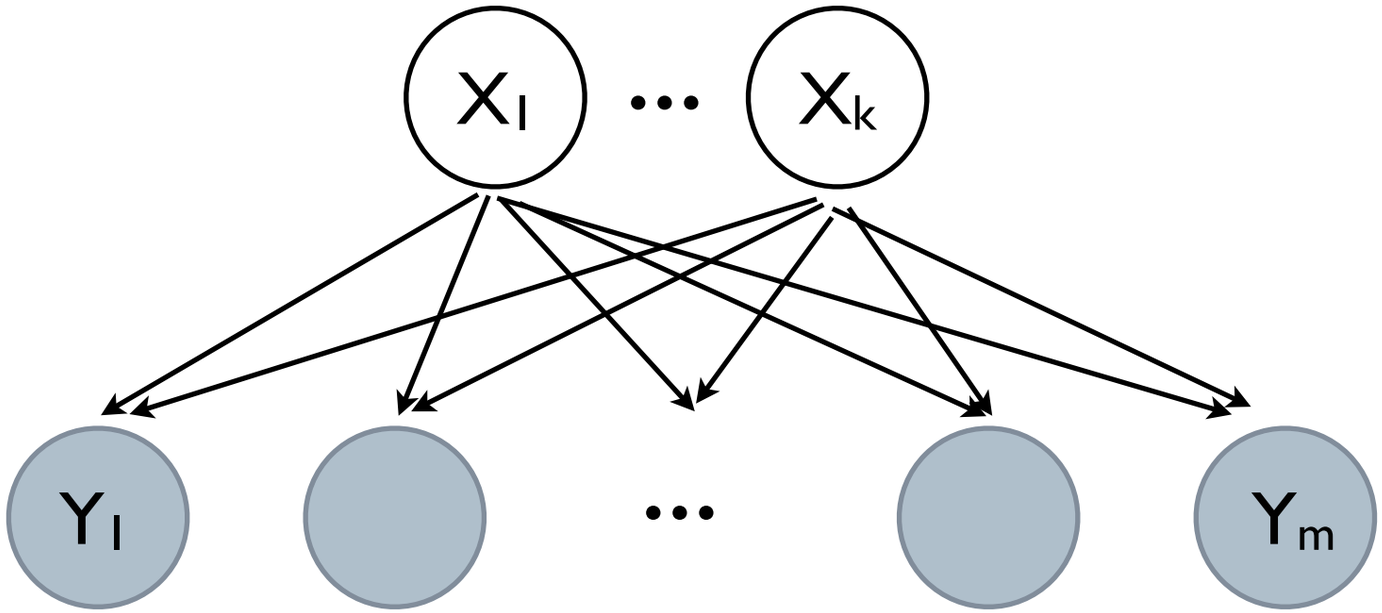
Graphs are a common and useful shorthand for representing probabilistic models with conditional independence

used to encode causal structure

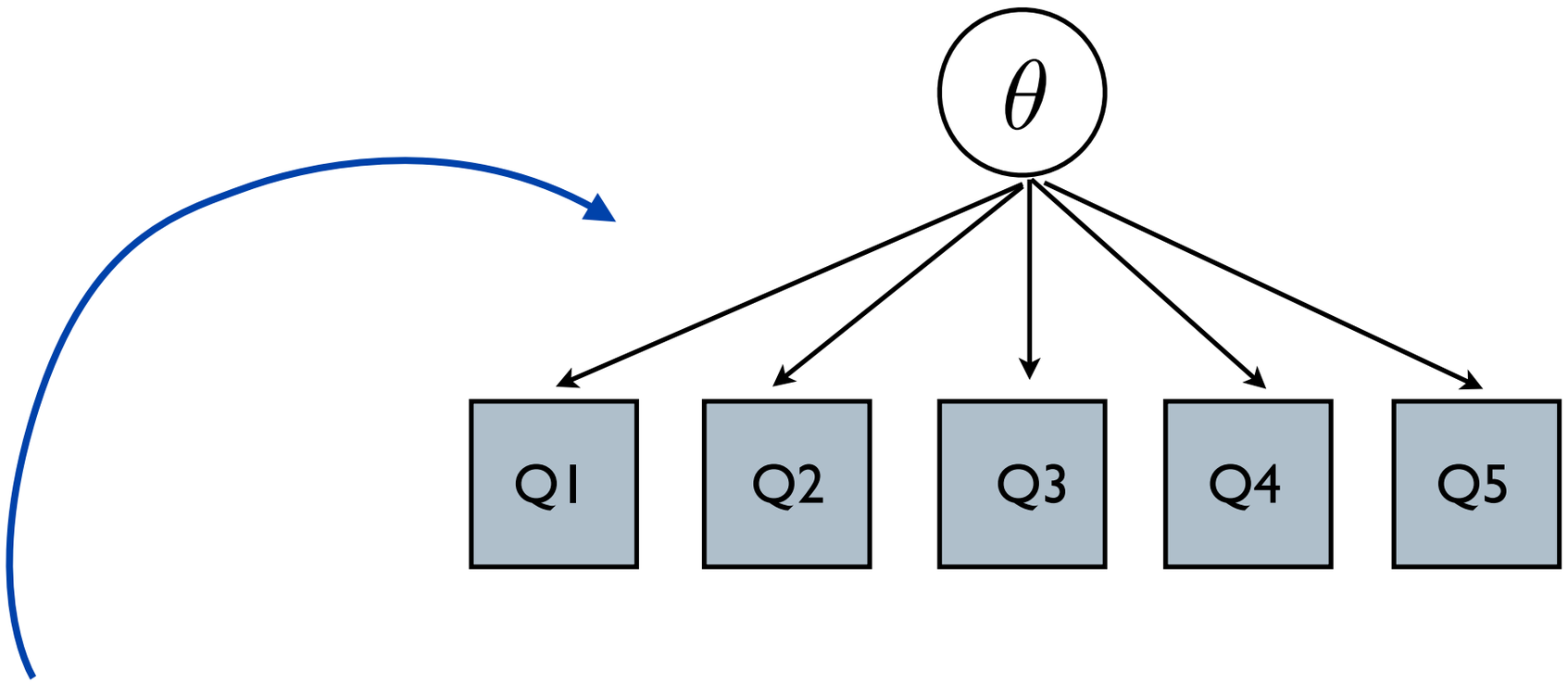
NB: because they are shorthand, there is sometimes ambiguity.



Factor Analysis



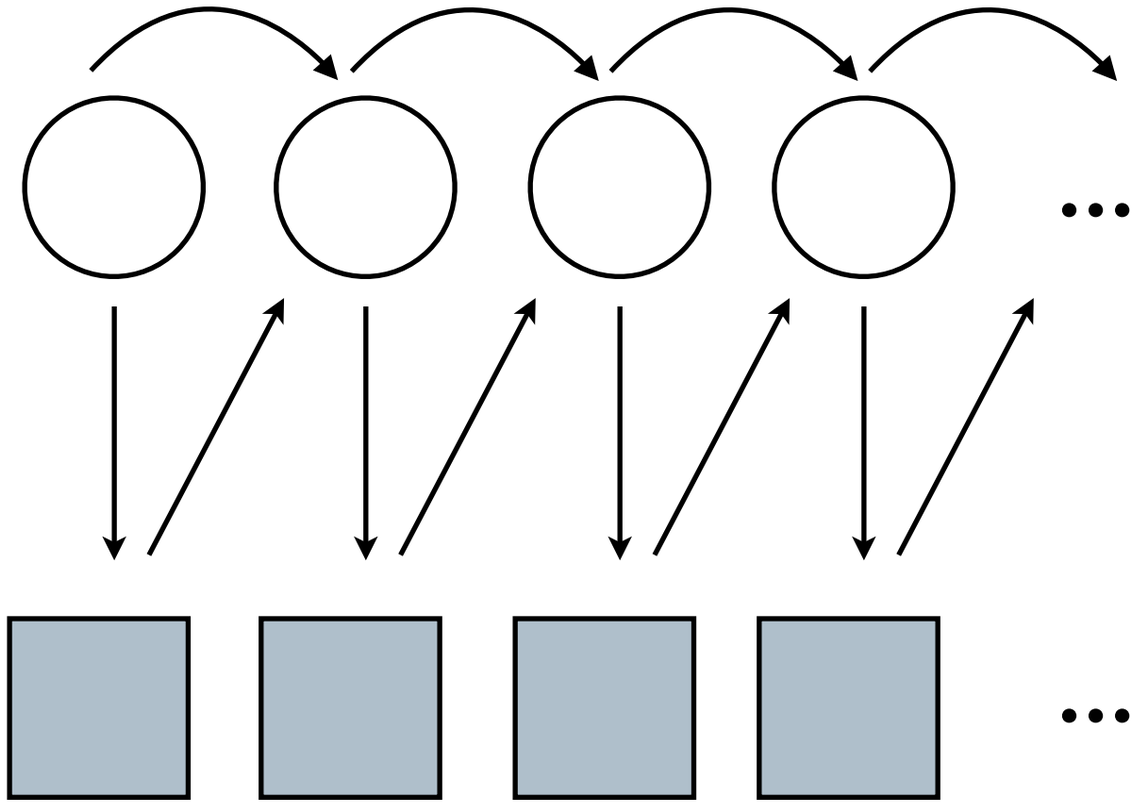
Test model



it's possible for these paths to represent the same probabilities or independent probabilities (more on this later)

Dynamic Bayesian Network (e.g. Hidden Markov Model)

for modeling a changing state, e.g. learning



Classical Test Theory vs Item Response Theory

true score $X = T + E$

reliability $\rho^2_{XT} = \frac{\sigma^2_T}{\sigma^2_X}$

$P(x^{(1)}|\theta, \xi) \quad Q = 1 - P$

$$L(\theta, x_1^{(0)}, x_2^{(1)}) \propto P(x_1^{(0)}, x_2^{(1)}|\theta, \xi_1, \xi_2)$$
$$= P(x_1^{(0)}|\theta, \xi_1)P(x_2^{(1)}|\theta, \xi_2)$$
$$= Q(x_1^{(1)}|\theta, \xi_1)P(x_2^{(1)}|\theta, \xi_2)$$

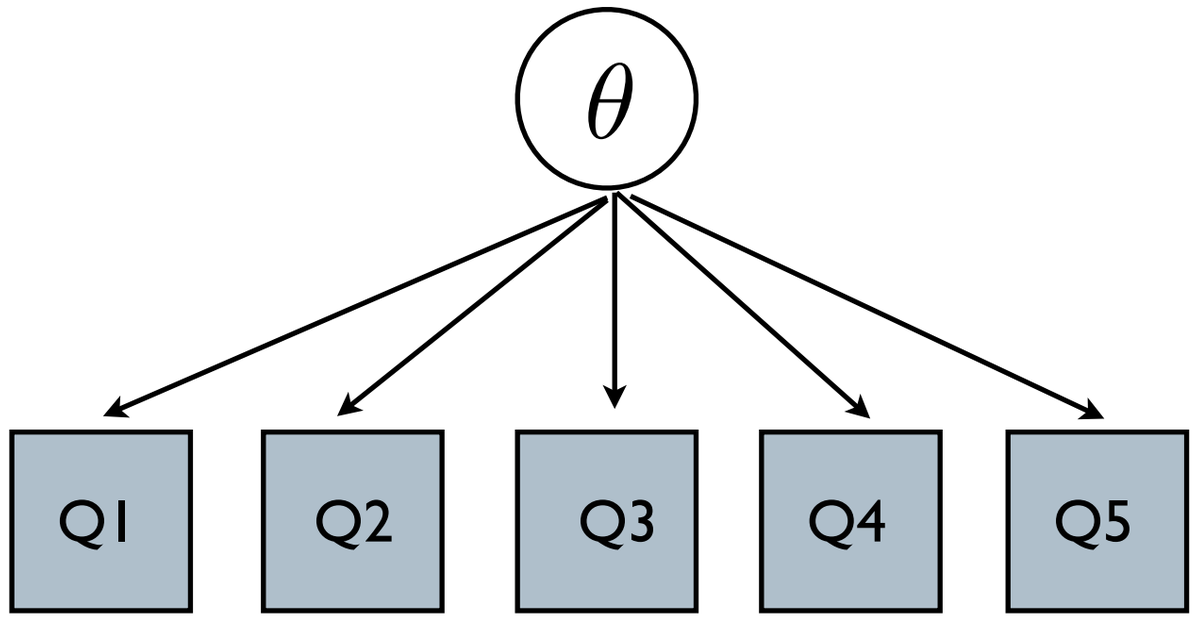
$\hat{\theta} = \arg\max_\theta L(\theta)$ skill (ability)

$I(\theta) = \sum P_i(\theta)Q_i(\theta)$ test information

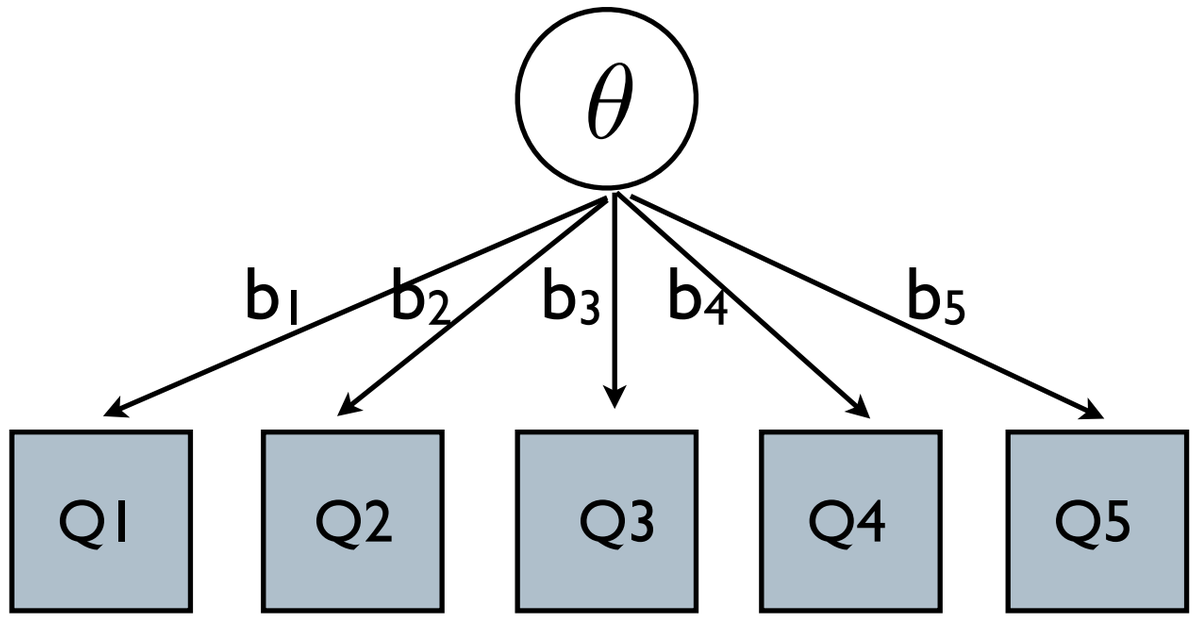
student-test vs. student-item

boils down to this difference in interaction granularity

Classical Test Theory



Item Response Theory



Item Response Theory

coming to a discipline-based education research journal near you!

e.g. physics education

G. Morris et al., *Am J Phys* (2006)
Y. Lee et al., *Phys Rev ST–PER* (2008)
J. Marshall, E. Hagedorn, and J. O'Connor, *Phys Rev ST–PER* (2009)
L. Ding, and R. Beichner, *Phys Rev ST–PER* (2009)
J. Wang, and L. Bao, *Am J Phys* (2010)
C. S. Wallace, and J. M. Bailey, *Astronomy Education Review* (2010)
C. N. Cardamone et al., in *PERC Proceedings* (2011)

Perhaps IRT appeals to scientists' notion of a *best* instrument for the job when items are essentially hierarchical (cf. Guttman scale),
but that's not the only option.

IRT was designed as an improved solution to testing problems

The goal is an ability score for the examinee
independently of which questions are selected from an item pool
(useful for high-stakes tests and also CAT)

"to describe the items by item parameters and the examinees by examinee parameters in such a way that we can predict probabilistically the response of any examinee to any item, even if similar examinees have never taken similar items before."

- F. Lord

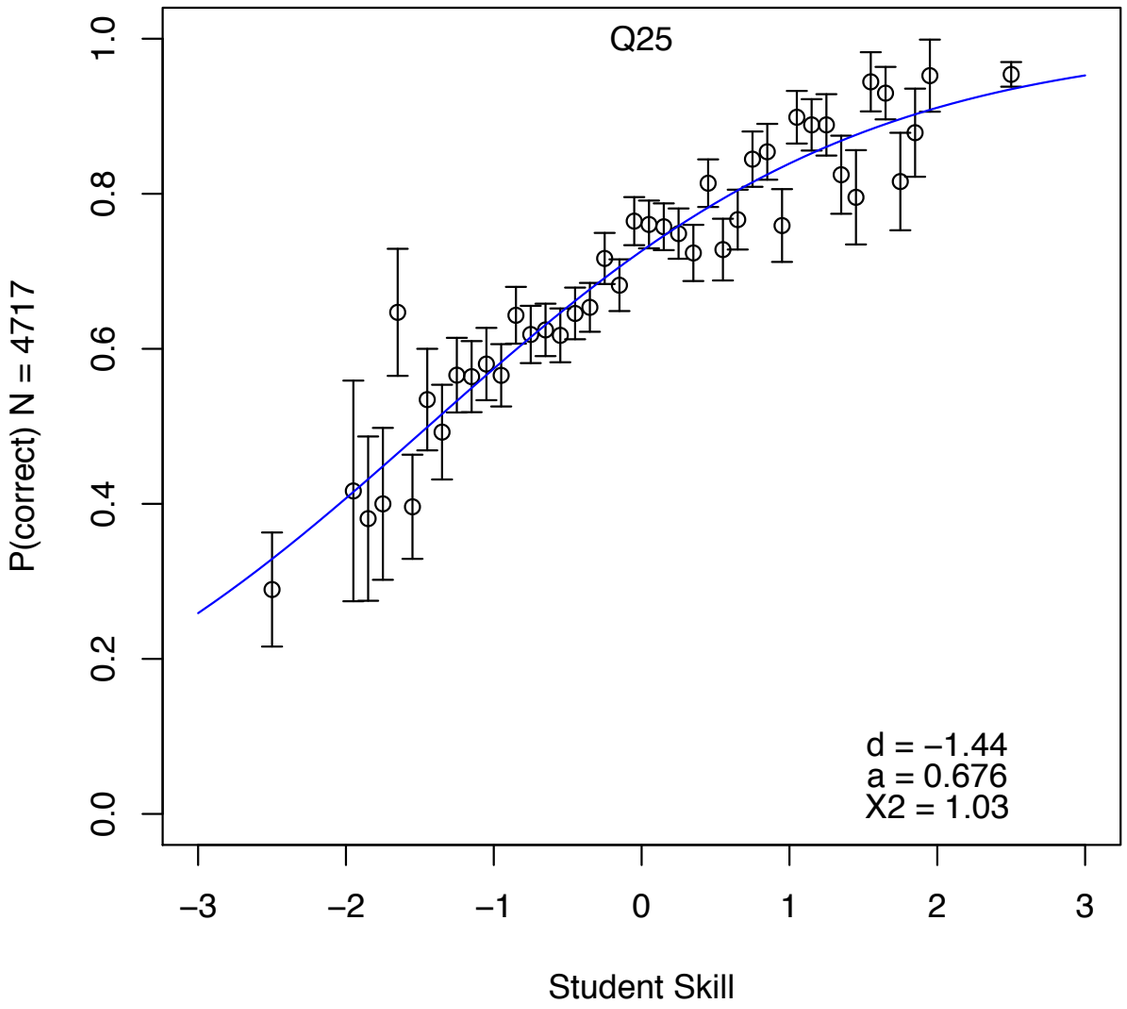
More accurate, and with fewer items, than raw scores.

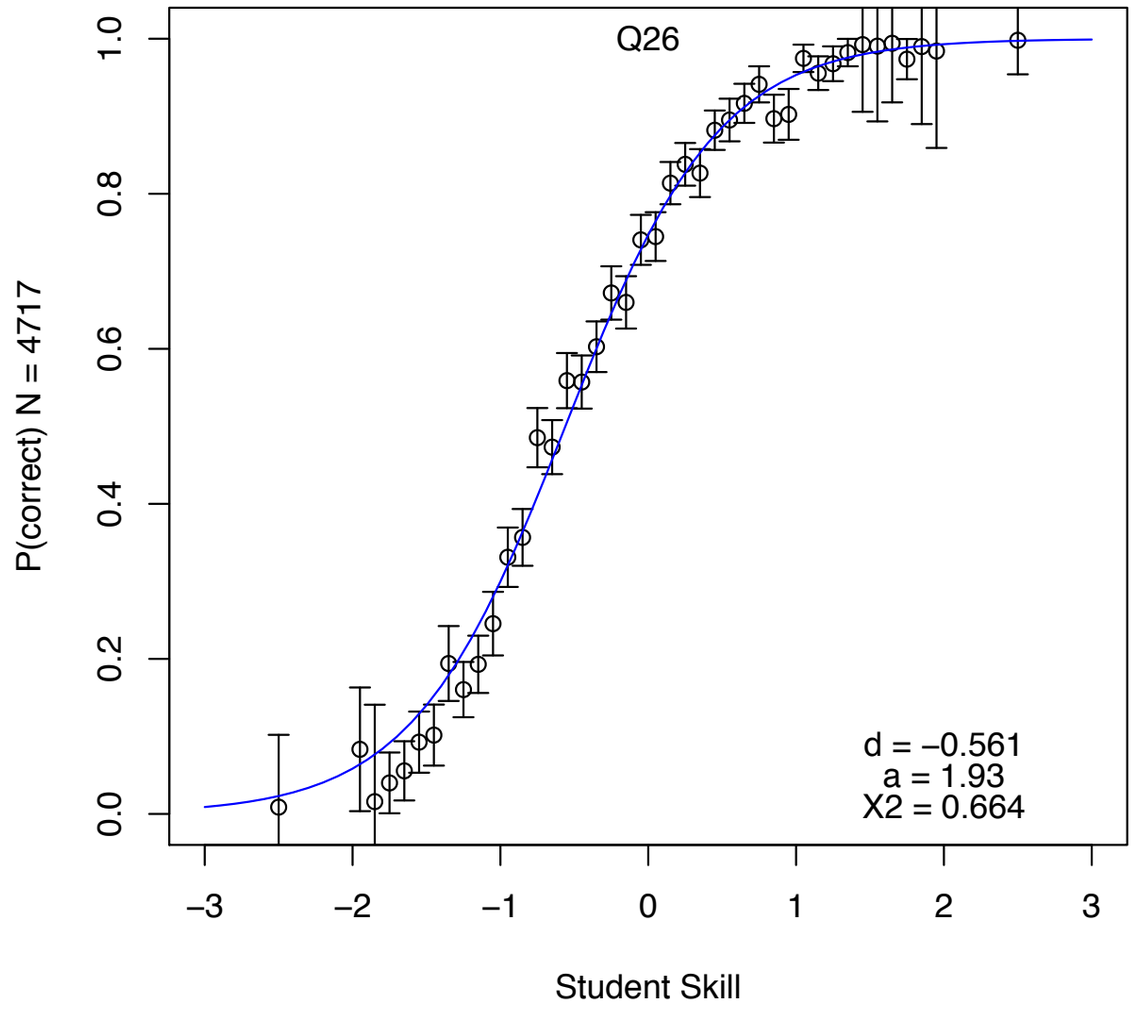
Measures items as well as students, and on the same scale.

IRT analysis reveals both "faulty" *and* highly discriminating items

But: there are *many* IRT models/methods, and details are fussy.

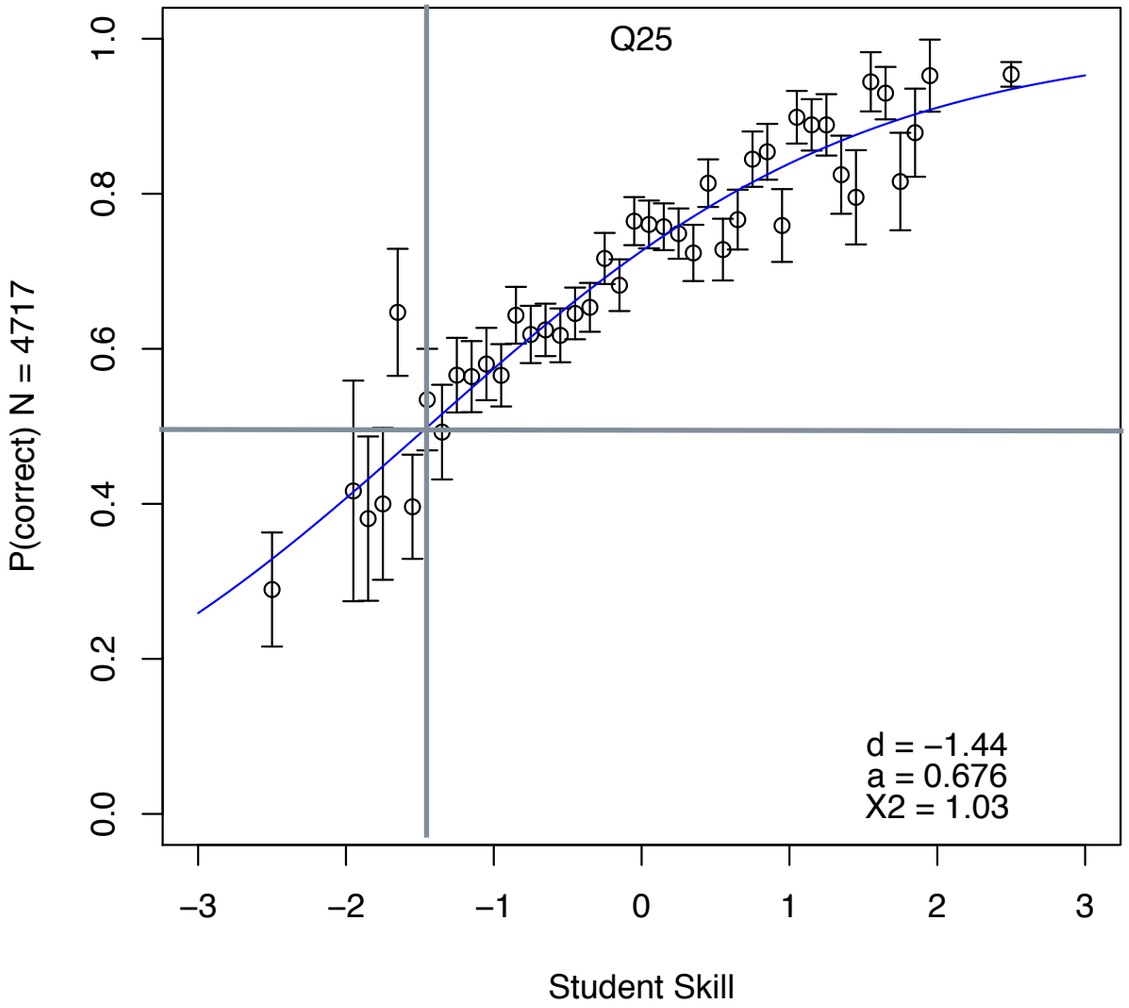
Some typical Item Response Curves

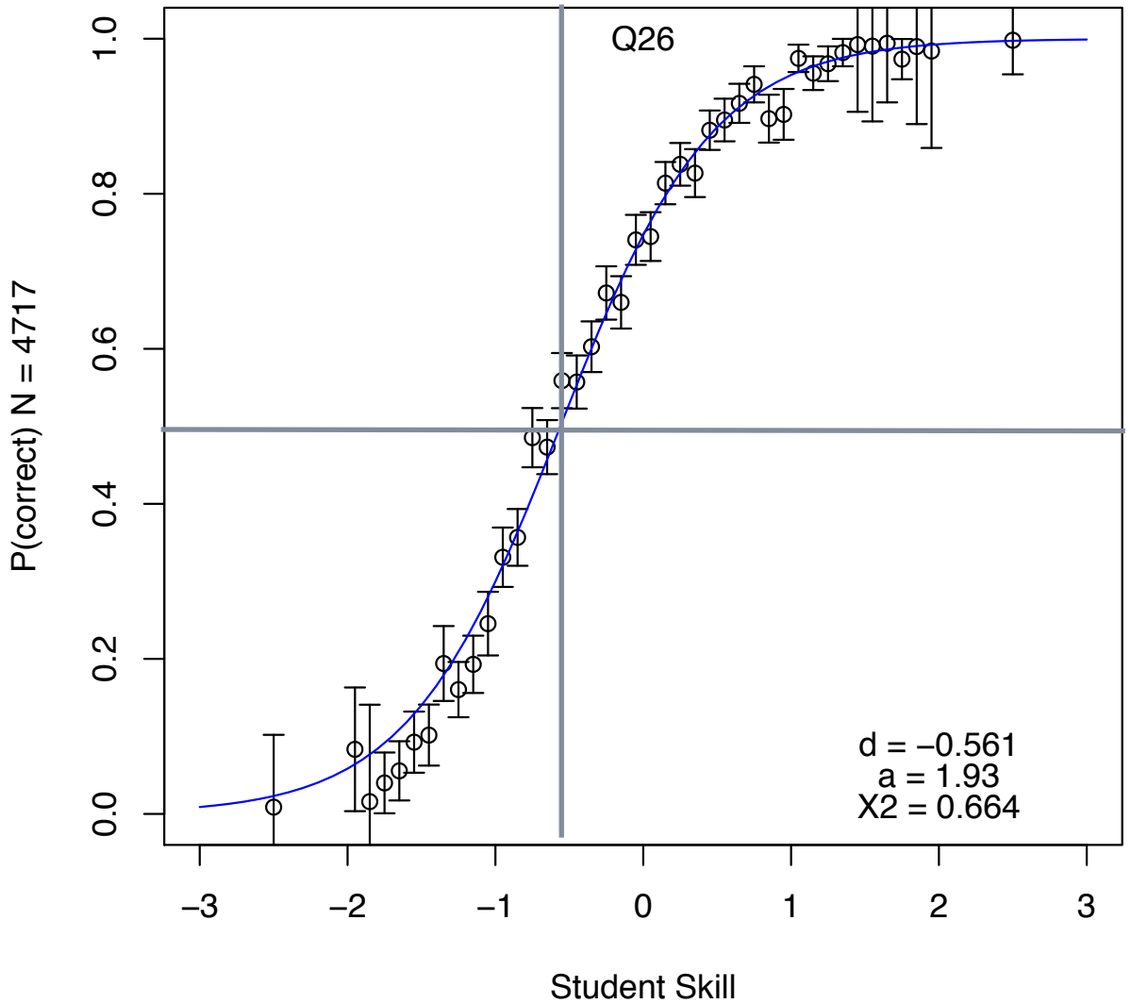




Mechanics Baseline Test (MIT)

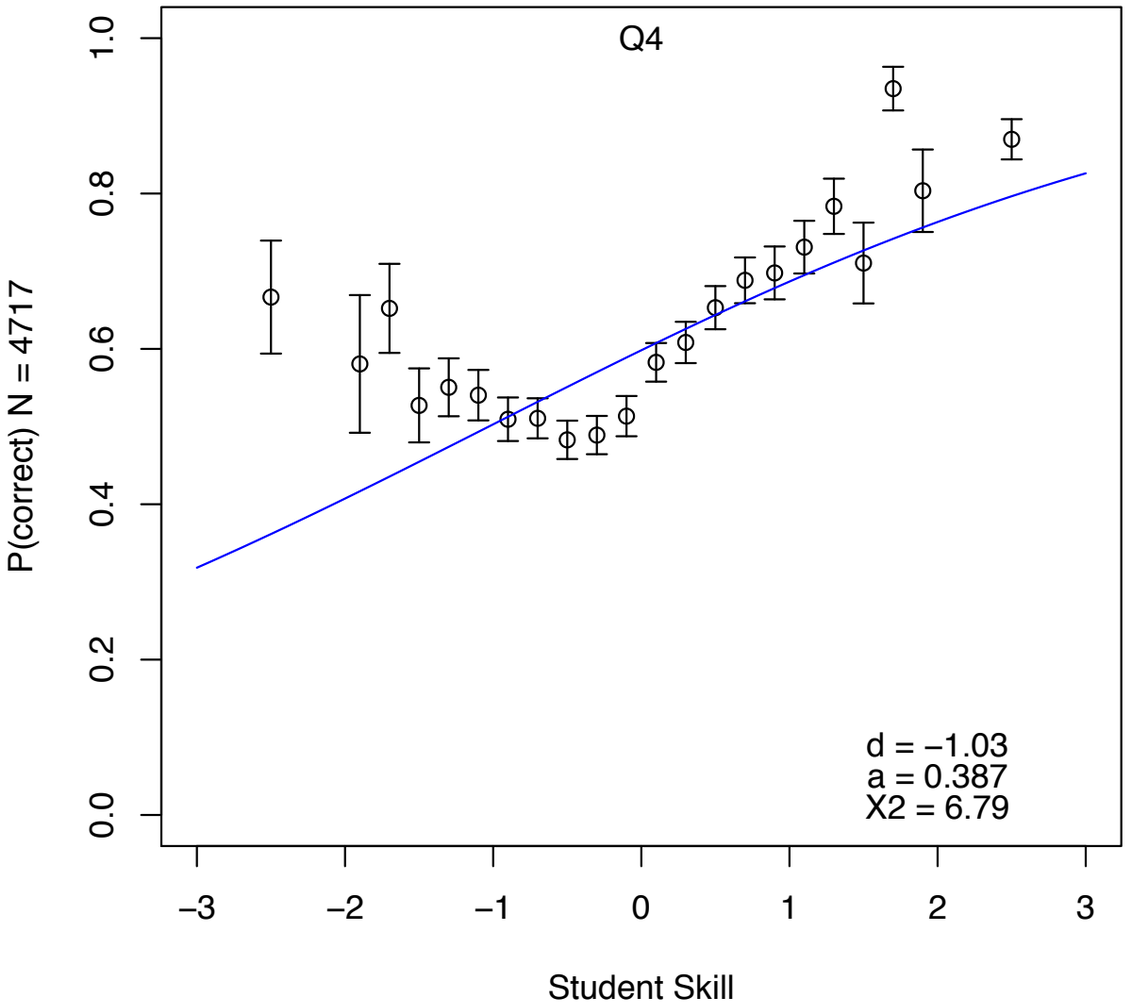
Some typical Item Response Curves

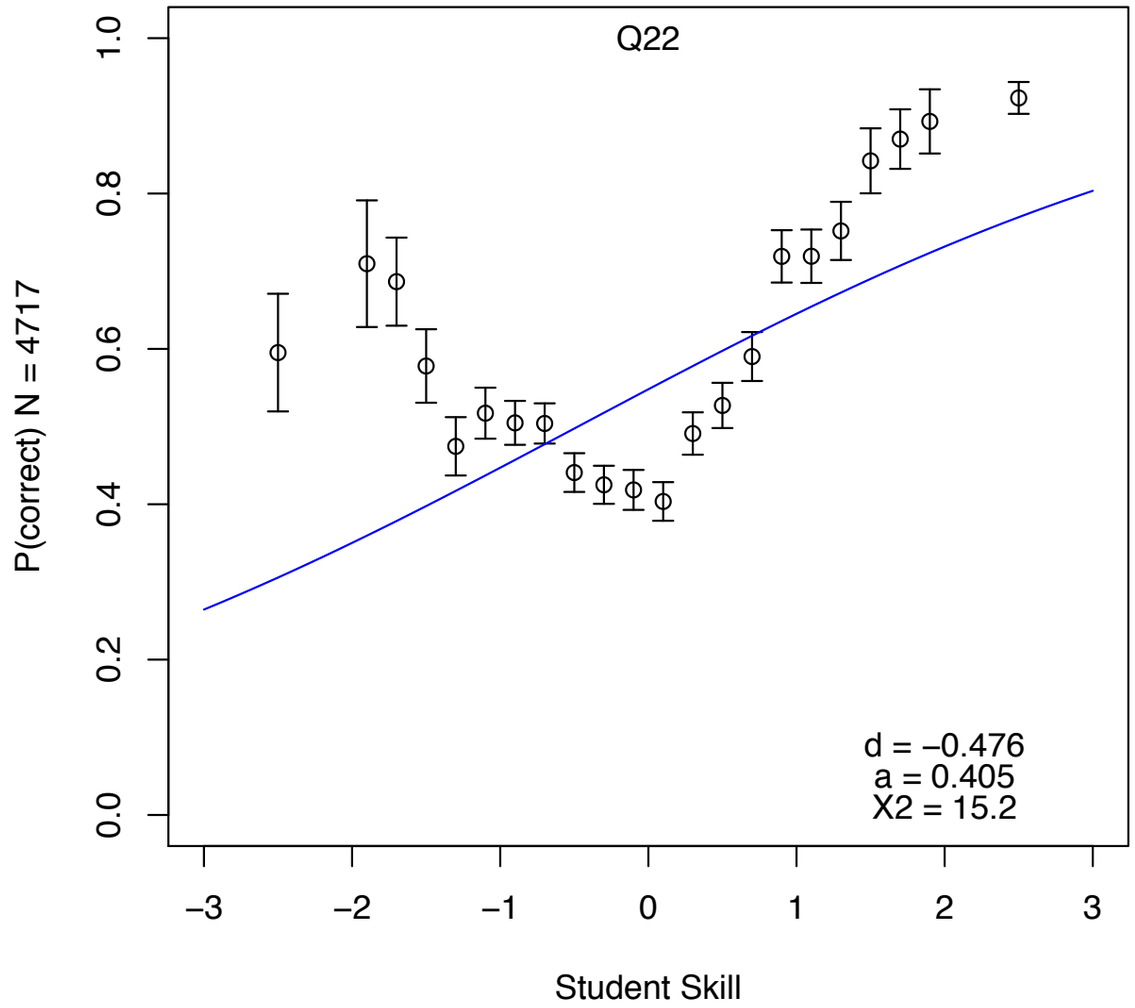




Mechanics Baseline Test (MIT)

And some pathological ones





ambiguous questions, not model fail!

misreading + common misconception -> correct response

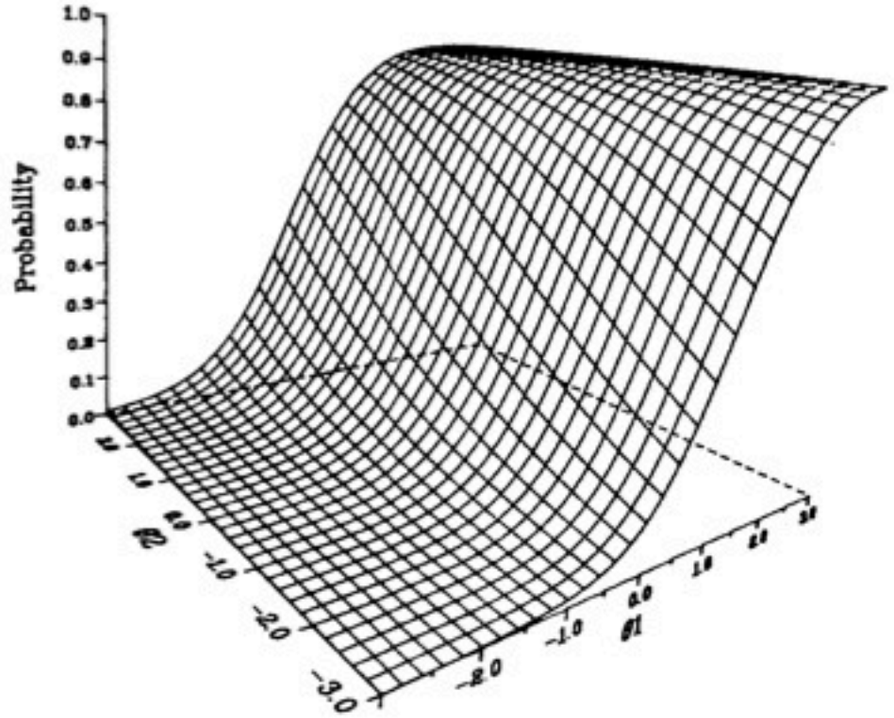
(Cardamone et al. PERC 2011)

2-dimensional 2PL

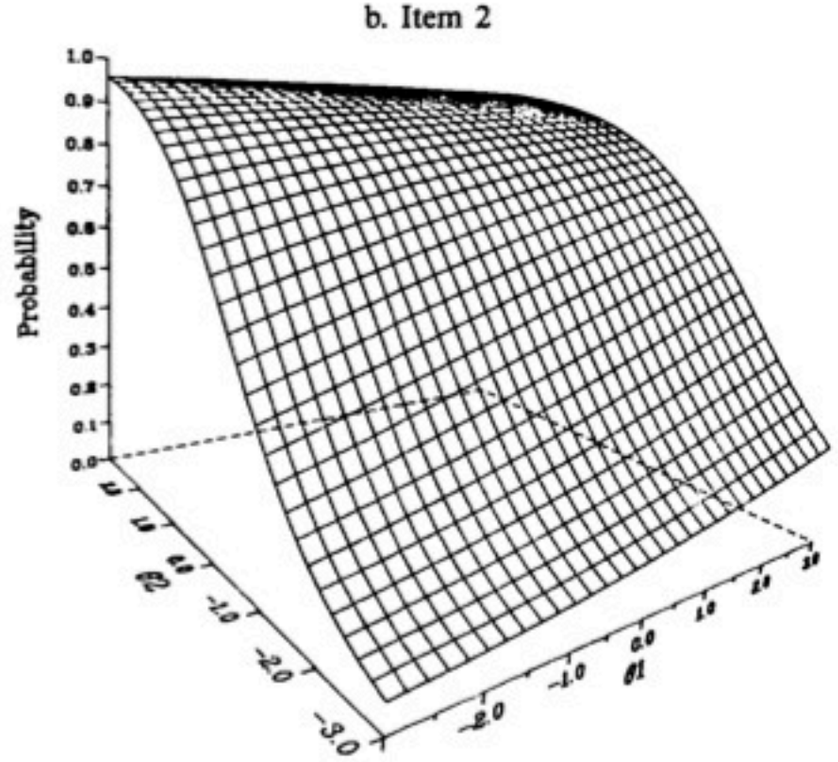
Item Characteristic Surfaces

Figure 1
Response Surfaces for Items That Vary in Discriminating Power and Dimension Assessed

a. Item 1



b. Item 2



source:
Reckase, McKinley (1991)

What exactly is meant by dimensionality of skill?

Dimensionality = number of parameters used to model a student's skill (over a domain)

Use of one final grade *implies* "unidimensionality"

A *multidimensional* basis can mean many things:
- topics (energy conservation or rigid body motion, etc.)
- conceptual vs. procedural knowledge
- language/reading ability vs. math proficiency
- problem types (graphing, algebraic numeric, analytical, etc.)
- something else...

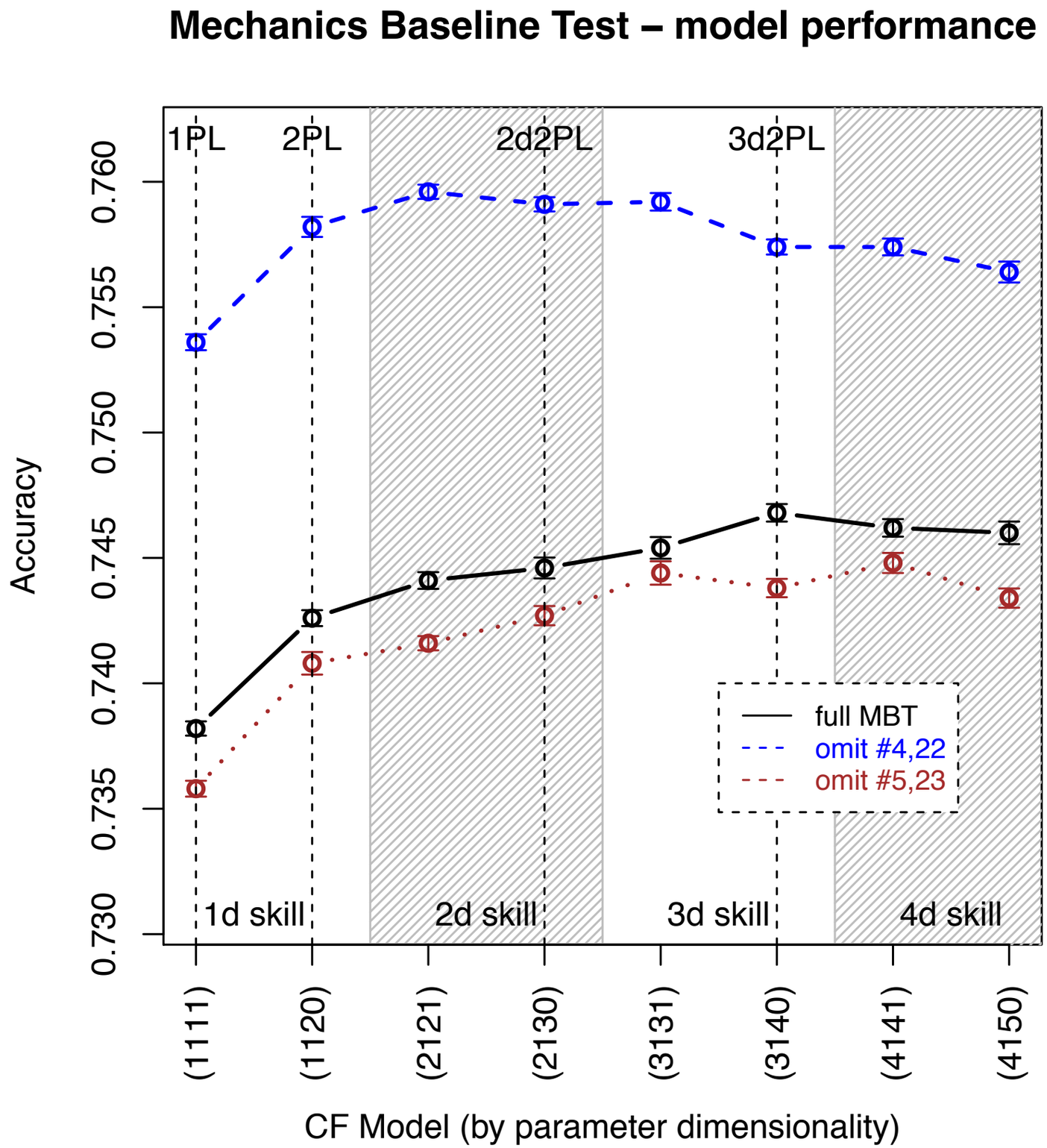
We use a technique called *collaborative filtering* to look for the "best" number of parameters to use in terms of predicting the correct/incorrect response data in a held-out (cross-validation) set.

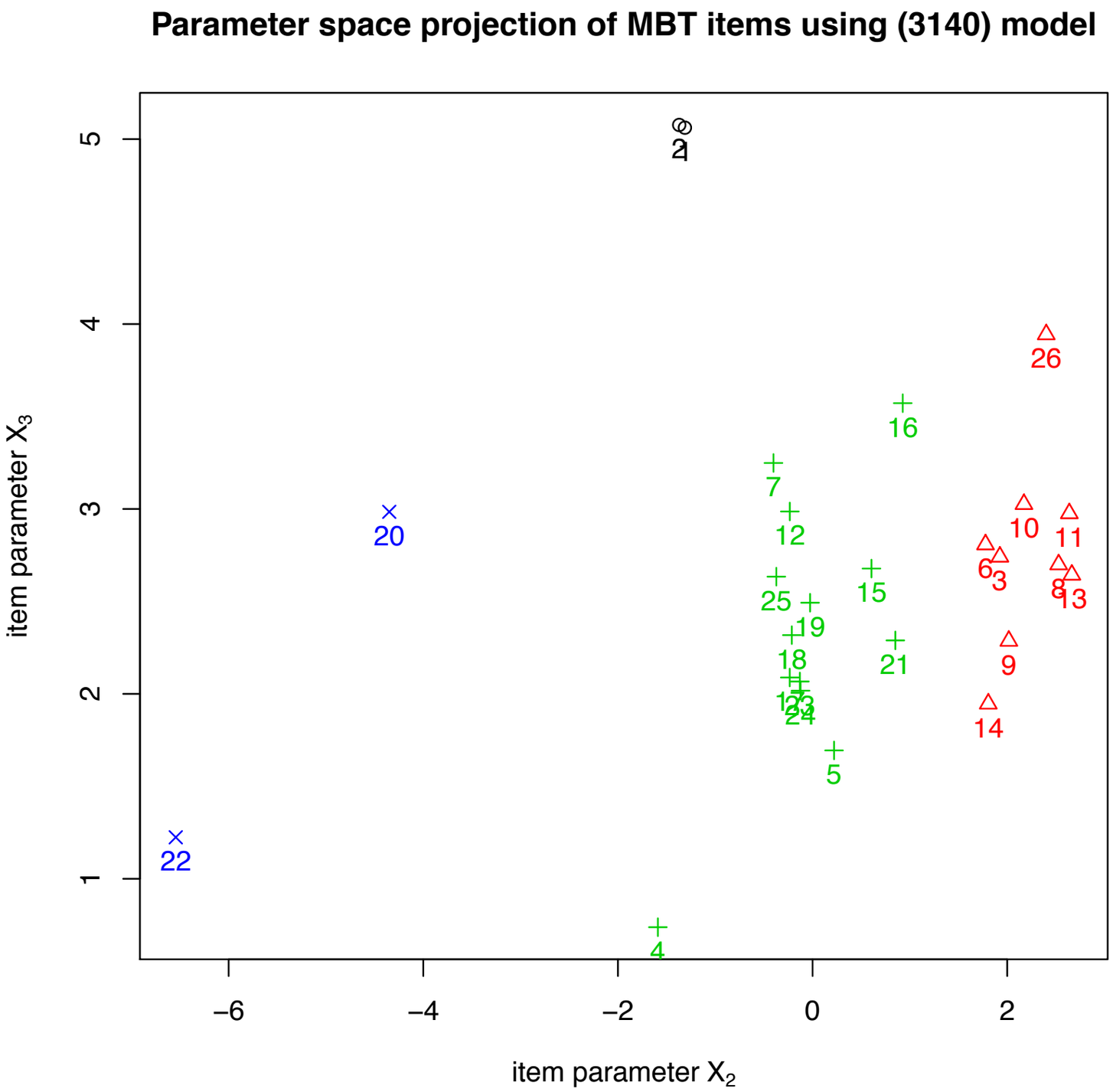
(We are not specifying any basis.)

MBT at MIT
2005-2009

Pre & Post
N=4700

dimensionality?
it depends





Q1 & Q2 cluster

Q4 & Q22 *may* be outliers

Q20 is the only work-energy question

Guidelines in scale development (DeVellis, 2003)

Step 1. Determine clearly what it is you *want* to measure

Step 2: Generate an item pool

Step 3: Determine the format for measurement

Step 4: Have the initial item pool reviewed by experts

Step 5: Consider inclusion of validated items

Step 6: Administer items to a development sample

Step 7: Evaluate the items (item performance, factor analysis, alpha)

Step 8: Optimize scale length

"Advanced technologies and statistical methods aren't sufficient. One must design a complex assessment from the very start around the inferences one wants to make, the observations one needs to ground them, the situations that will evoke those observations, and the chain of reasoning that connects them."

Mislevy, Steinberg and Almond (channeling Messick)

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