The University of Georgia

Diagnostic Measurement: Theory, Methods, and Applications

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Course Website: http://wp.me/p3nkOf-nu

Workshop Overview

INTRODUCTIONS/COURSE MATERIALS: 8:00 – 8:15am

- **Section 1**: **Diagnostic Measurement Introduction** (8:15 – 9:45am)
  - Conceptually, how is "diagnostic" measurement different from more traditional measurement?
  - Why/when would you use diagnostic classification models (DCMs)?

BREAK: 9:45-10:00am

- **Section 2: Theoretical Framework of DCMs** (10:00 – 11:45am)
  - Latent variables in diagnostic measurement
  - Specification of a general DCM, the log-linear cognitive diagnosis model (LCDM)
- **Questions/Discussion** (11:45-12:00 noon)

LUNCH: 12:00-1:00pm

- **Section 3: DCMs in Practice** (1:00 – 2:30 pm)
  - Applying DCMs to a test of rational numbers
  - How-to for estimating DCMs with Mplus

BREAK: 2:30-2:45pm

- **Section 4: Structural Model Specifications**(2:45 – 3:45pm)
  - Specifying structural model
  - Making alterations in Mplus
- **Section 5: Questions/Discussion** (3:45 – 4:45pm)
  - Discussions about our/your practical experiences with DCMs
  - Opportunity to ask about more specific content not covered in general introduction

EVALUATE TRAINING SESSION: 4:45-5:00pm

The University of Georgia

Conceptual Foundations of Diagnostic Measurement

Session 1

Session Overview

- Key definitions
- Conceptual examples
- Why diagnostic models should be used instead of traditional classification methods
- Concluding remarks

Session 1: Conceptual Foundations of Diagnostic Measurement

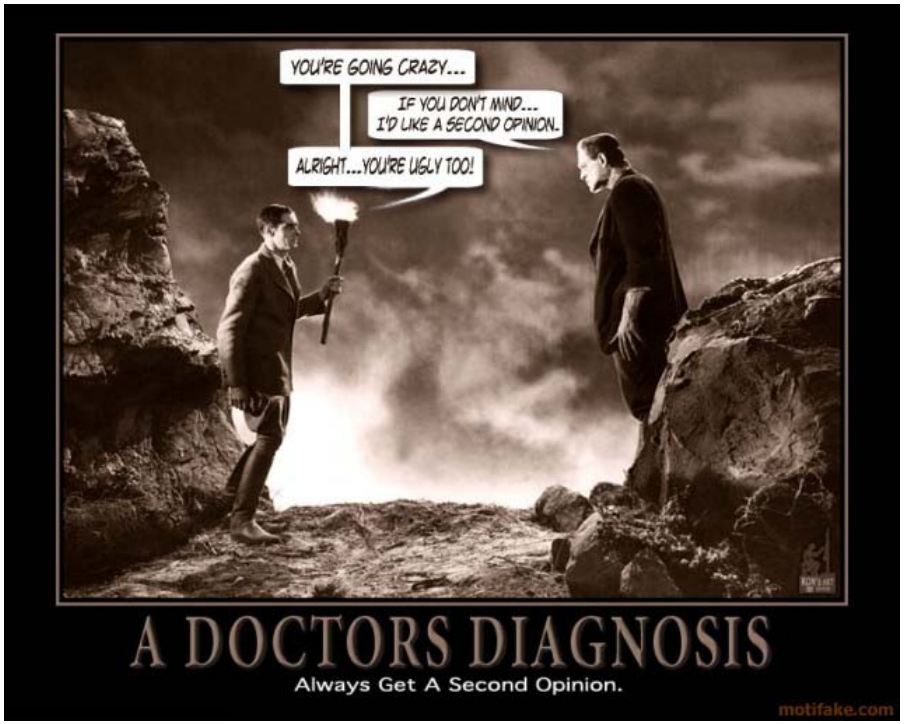
DEFINITIONS

What are Diagnoses?

- The word and meaning of diagnosis is very commonly used in language

- The roots of the word diagnosis:
  - *gnosis*: to know
  - *dia*: from two

- Meaning of diagnoses are deeply ingrained in our society
  - Seldom merits a second thought



Definitions

- *American Heritage Dictionary* definition of *diagnosis*:
  - Generally
    - (a) A critical analysis of the nature of something
    - (b) The conclusion reached by such analysis
  - Medicine
    - (a) The act or process of identifying of determining the nature and cause of a disease or injury through evaluation of a patient's history, examination, and review of laboratory data
    - (b) The opinion derived from such an evaluation
  - Biology
    - (a) A brief description of the distinguishing characteristics of an organism, as for taxonomic classification (p. 500)

Diagnosis: Defined

- A diagnosis is the *decision* that is being made based on information

- Within psychological testing, providing a test score gives the information that is used for a diagnosis

  - BUT, the score is not the diagnosis

  - For this workshop, a diagnosis is by its nature *discrete*
    - Classification

Day-to-Day Diagnosis

- Decisions happen every day:
  - Decide to wear a coat or bring an umbrella
  - Decide to study
  - Decide what to watch on TV tonight

- In all cases:
  - Information (or data) is collected
  - Inferences are made from data based on what is likely to be the true state of reality

Diagnosis (Formalized)

- In diagnostic measurement, the procedures of diagnosis are formalized:
  - We make a set of observations
    - Usually through a set of test questions
  - Based on these questions we make a decision as to the underlying state (or states) of a person
    - The decision is the diagnosis

Diagnosis (Formalized)

- Diagnoses featured in this workshop:
  - Educational Measurement
    - The competencies (skills) that a person has or has not mastered
      - Leads to possible tailored instruction and remediation
  - Psychiatric Assessment
    - The DSM criteria that a person meets
      - Leads to a broader diagnosis of a disorder

Workshop Terminology

- **Respondents**: The people from whom behavioral data are collected
  - Behavioral data considered test item responses for workshop
  - Not limited to only item responses
- **Items**: Test items used to classify/diagnose respondents
- **Diagnostic Assessment**: The method used to elicit behavioral data
- **Attributes**: Unobserved categorical characteristics underlying the behaviors (i.e., diagnostic status)
  - Latent variables linked to behaviors diagnostic classification models
- **Psychometric Models**: Models used to analyze item response data
  - Diagnostic Classification Models (DCMs) is the name of the models used to obtain classifications/diagnoses

Diagnostic Classification Model Names

- Diagnostic classification models (DCMs) have been called many different things
  - Skills assessment models
  - Cognitive diagnosis models
  - Cognitive psychometric models
  - Latent response models
  - Restricted (constrained) latent class models
  - Multiple classification models
  - Structured located latent class models
  - Structured item response theory

Psychometric Soapbox

- DCMs are but a small set of tools that must be adapted for a common purpose
  - Part of a methodological toolbox that is used to classify respondents
  - Should also include content experts and end-users of the diagnoses

- DCMs link empirical observations and respondents characteristics
  - The models are only as good as underlying theories

Session 1: Conceptual Foundations of Diagnostic Measurement

CONCEPTUAL EXAMPLE

Motivation for DCMs

- Testing more today that we ever have
  - Accountability movement
- What are we getting out of testing?
  - Often, a single score
  - How useful is this score:
    - To make decisions about students?
    - To reflect students' knowledge base or deficiencies?
    - To inform instruction?
- What if a test didn't give a single score?
  - Instead made decisions about students
    - With respect to multiple, discrete facets of a content area
- A **diagnostic classification model** is a tool that can be used to make these kinds of decisions

What do we learn from assessments?

Video Clip from 2010 Techonomy Conference; Accessed from http://techonomy.com/

Diagnostic Need in Education

- In education, there is a need for more specific feedback about what students do and do not understand
- Imagine if we could
  - Diagnose mastery with respect to a set of skills
    - Complement standards-based curriculum (K-12)
    - Monitor students' strengths and weaknesses
    - Place students into appropriate courses
  - Tailor instruction to individual needs
- Concept is not contentious
  - Common Core calls for diagnostic assessments
    - NCLB required diagnostic score reports
  - Teachers seek more diagnostic score reports

TRADITIONAL MEASUREMENT MODELS

Traditional Measurement Concepts

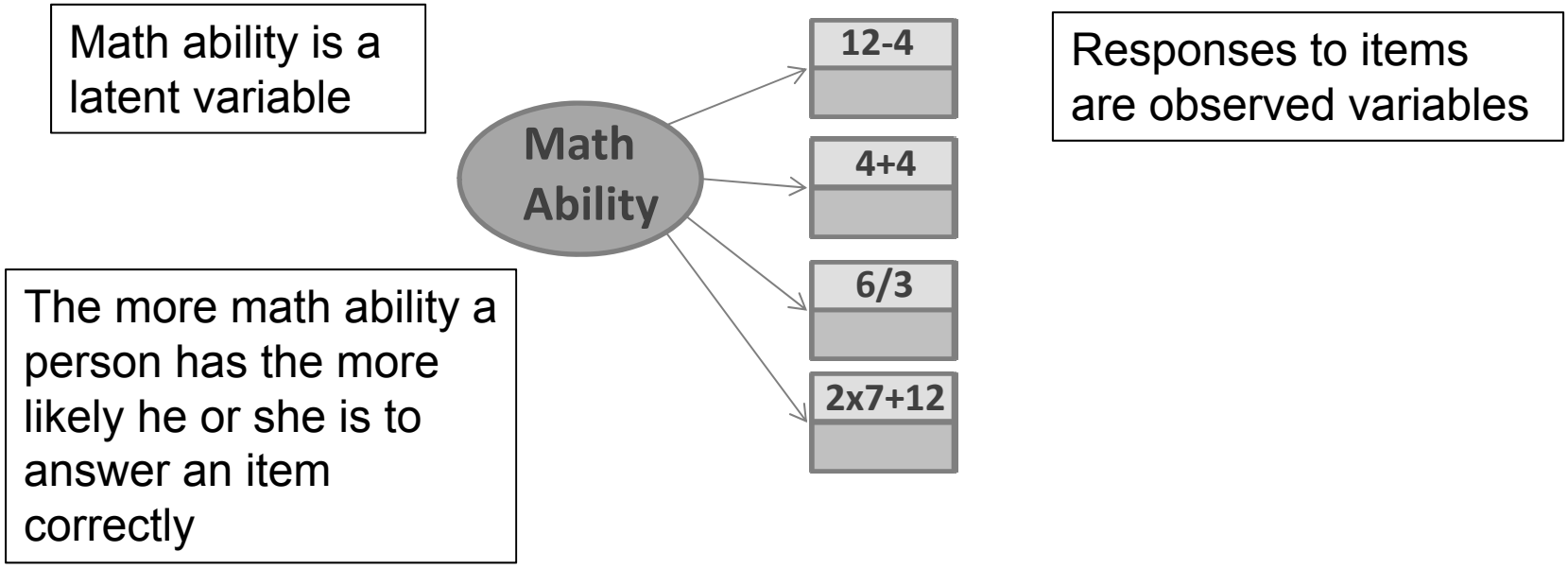
- Imagine that an elementary teacher wants to test basic math ability

- Using traditional psychometric approaches, the teacher could estimate an ability or test score for each respondent
  - Classical Test Theory: Assign respondents a test score
  - Item Response Theory: Assign respondents a latent (scaled) score

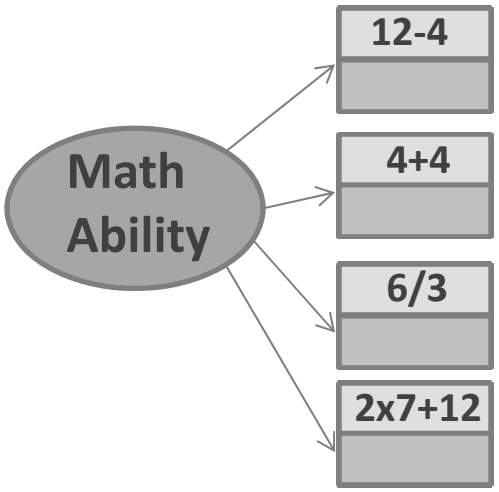
- By knowing each respondent‘s score, the students are ordered along a continuum

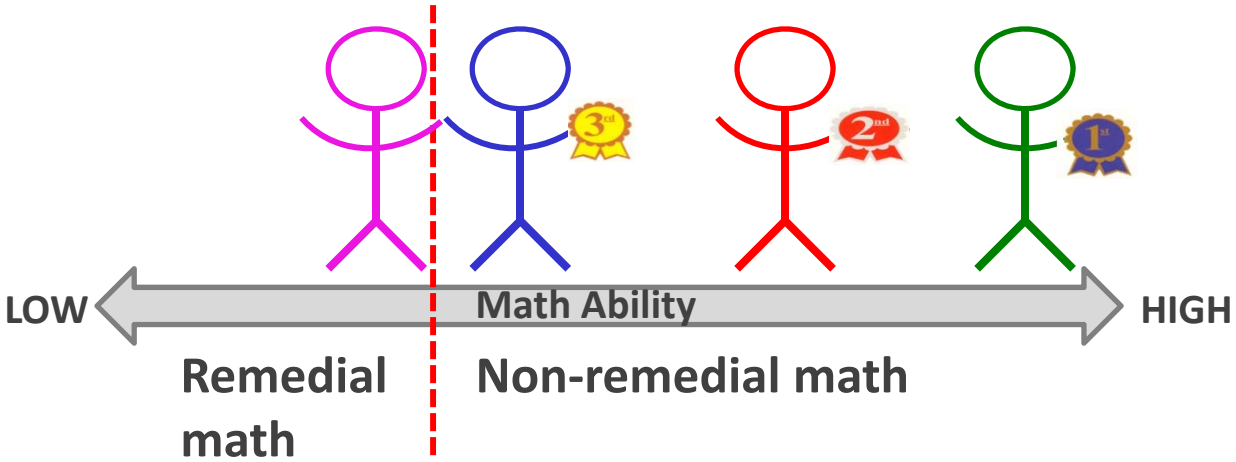
Traditional Measurement Models

- Traditional testing procedures measure an **overall** ability in an area with a **continuous** latent variable



Traditional Testing and Classification Methods





- Information from Continuum:
  - Spencer has more math ability than Sue
  - Juan scored in the 70th percentile
  - Hugh scored a 240 on the test
- Diagnosis from Cut Score:
  - Sue scored below the cut score
  - Sue will take the remedial math course

Traditional Psychometrics

- What results is a (weak) ordering of respondents
  - Ordering is called weak because of error in estimates
  - Hugh>Juan>Spencer>Sue

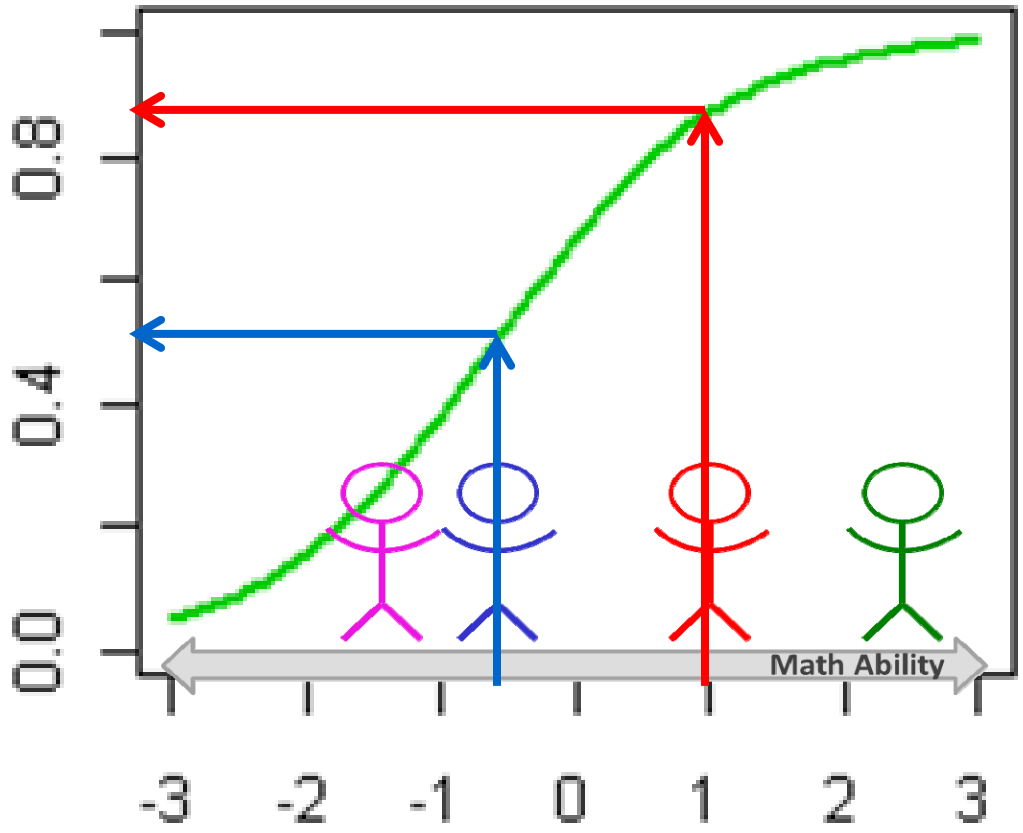
- Questions that traditional psychometrics cannot answer:
  - Why is Sue so low?
    - How can we get her some help?
  - How much ability is “enough” to pass?
    - How much is enough to be proficient?
  - What math skills have the students mastered?
    - Which skills have they yet to master?

Item Characteristic Curve

- The item response is a function of a student's ability

The probability that Juan will answer this item correctly is .88.

The probability that Spencer will answer this item correctly is .52.



Multiple Dimensions of Ability

- As an alternative, we could have expressed math ability as a set of basic skills:
  - Addition
  - Subtraction
  - Multiplication
  - Division

Multiple Dimensions of Ability

- The set of skills represent the multiple dimensions of elementary mathematics ability

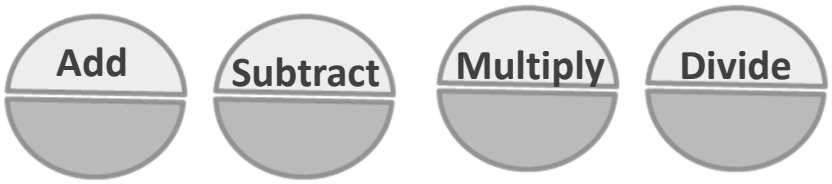
- Other psychometric approaches have been developed for multiple dimensions
  - Classical Test Theory - Scale Subscores
  - Multidimensional Item Response Theory (MIRT)

- Yet, issues in application have remained:
  - Reliability of estimates is often poor for most practical test lengths
  - Dimensions are often very highly correlated
  - Large samples are needed to calibrate item parameters in MIRT

DIAGNOSTIC MEASUREMENT MODELS

Math Ability Example: A Diagnostic Approach

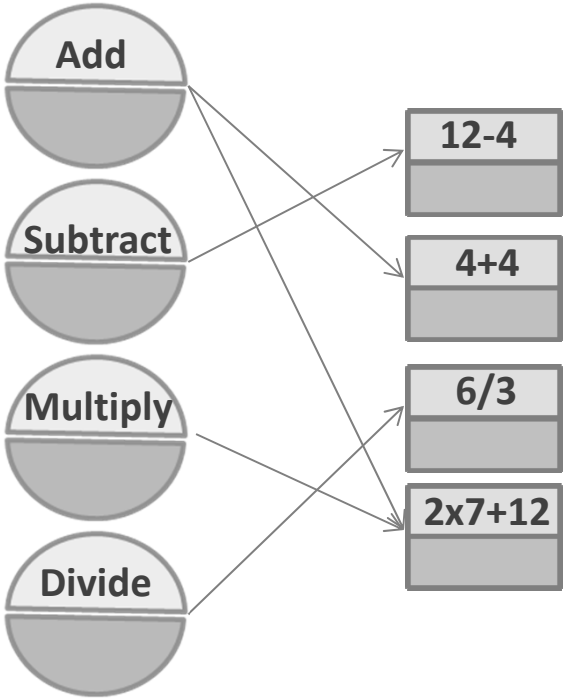
- Instead of measuring an overall math ability, "math" is expressed as a set of skills or ***attributes***:
  - Add
  - Subtract
  - Multiply
  - Divide



- These attributes are categorical latent variables
  - Not a continuum
- Attributes are often dichotomous
  - Two levels or groups or categories
  - The two groups may be labeled differently:
    - Mastery/non-mastery
    - Proficient/Emerging
    - Ready/not ready
  - Mastery of an attribute (α = 1) or non-mastery of an attribute (α = 0)

DCMs: A Conceptual Example

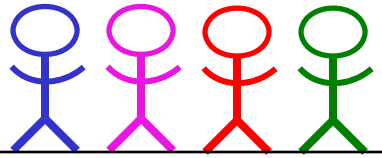
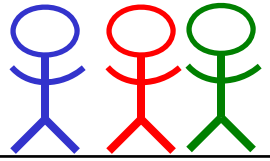
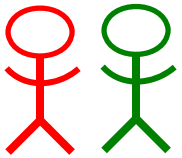
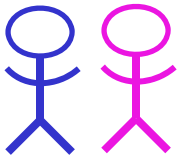
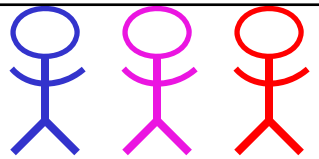
- What would our test look like?
  - Each item measures one or more attribute
- The attributes measured by each item are recorded in a **Q-matrix**
  - Describes whether an item measures an attribute (q = 1) or not (q = 0)
  - Mapping is established by content experts



	Add	Subtract	Multiply	Divide
12-4	0	1	0	0
4+4	1	0	0	0
6/3	0	0	0	1
2x7+12	1	0	1	0

Diagnostic Classification Models

- DCMs uses responses to items to place students into **groups** according to **multiple** skills
  - –No cut score is used to put students into groups; the model is built to do that

	Masters	Non-masters
Add		
Subtract		
Multiply		
Divide		

Diagnostic Classification Models

- Students receive skill-specific feedback

	Add	Subtract	Multiply	Divide
				
				
	.84	.76	.35	.28
				

Spencer has mastered addition and subtraction, but should improve his ability to multiply and divide.

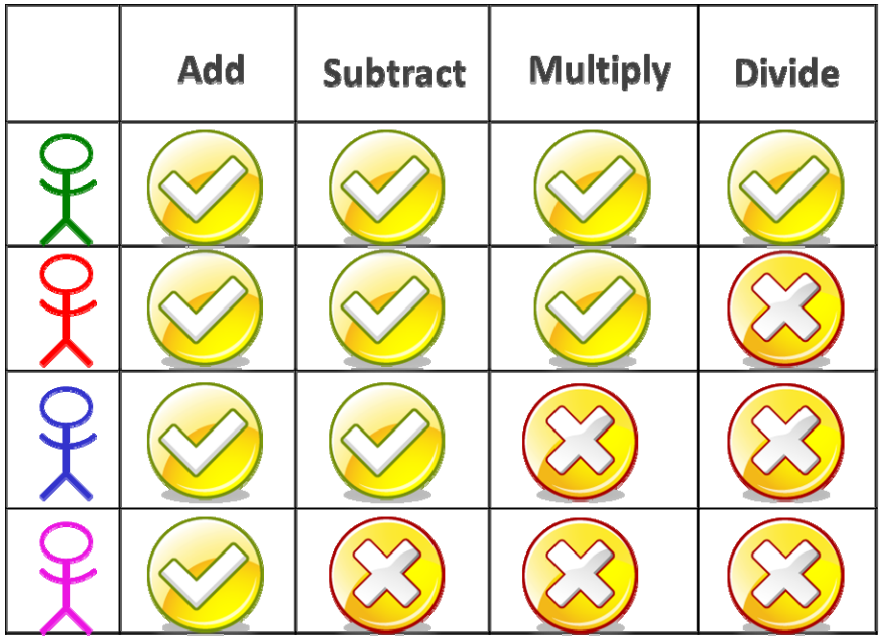
Or in Bill Gate-ese: Hey, Spencer you've got multiplication and division screwed up, but you're fine on addition and subtraction.

- The model provides a probability each attribute is mastered
- Notice there is no "score" in a traditional or grading sense

Possible Patterns of Attribute Mastery

The pattern of skills students have is often referred to as a mastery profile or an **attribute profile**

- 4 patterns below are 4 of the possible 16 profiles of mastery that exist if there are 4 attributes:



All possible patterns:

Pattern	Add	Sub.	Multiply	Divide
1	0	0	0	0
2	0	0	0	1
3	0	0	1	0
4	0	0	1	1
5	0	1	0	0
9	1	0	0	0
10	1	0	0	1
11	1	0	1	0
12	1	0	1	1
13	1	1	0	0
14	1	1	0	1
15	1	1	1	0
16	1	1	1	1

A classification of each individual skill results in a classification into one of these patterns

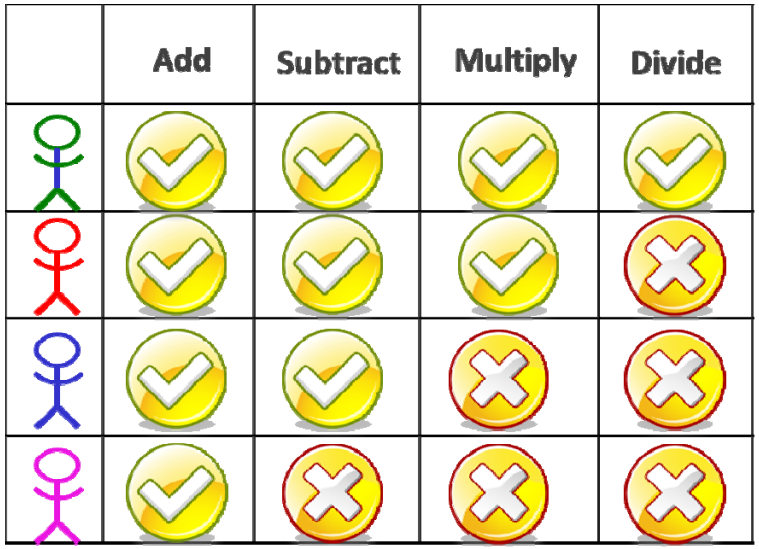
Expected Examinee Responses

Q-matrix

	+	-	x	/
12-4	0	1	0	0
4+4	1	0	0	0
6/3	0	0	0	1
2x7+12	1	0	1	0

- Given a student's profile of mastery and the set of skills measured by each item, we can determine how we expect a student to respond to each item.

Student Profiles



These students will likely answer the following items correctly:

All Items

Items 1, 2, 4

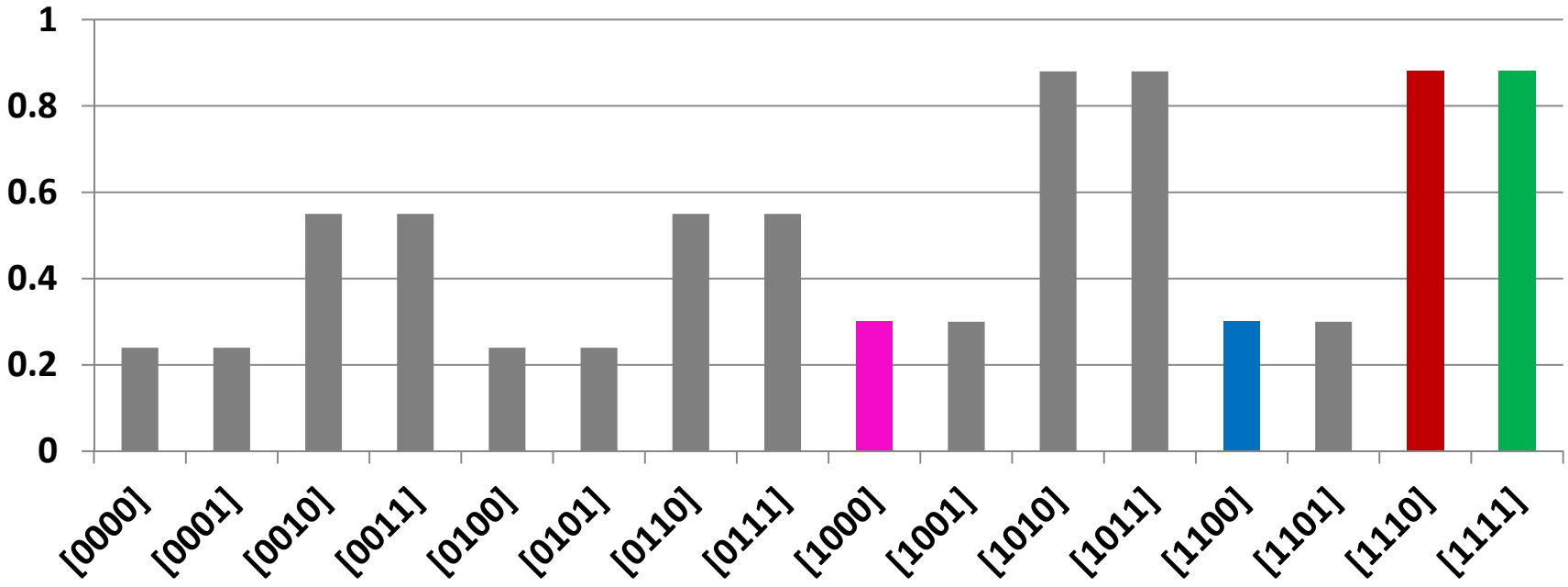
Items 1,2

Item 2

Which items a student answers correctly depends on (1) which attributes he or she has and, (2) which attributes are being measured by the item.

Item Characteristic Bar Chart

- Example item: 2 x 7 + 12 = ?
  - Measures Attribute 1 (addition) and Attribute 3 (multiplication)



- Juan's probability of correct response is .88
- Spencer's probability of correct response is .3

Traditional Score Report

- Example from Georgia's federally mandated end-of-course assessments

Criterion-Referenced Competency Tests (CRCT) • Spring 2009

Name: **JOHNSON, JENNY A**
GTID: **5678123499**
Gender: **F**
Grade: **5**

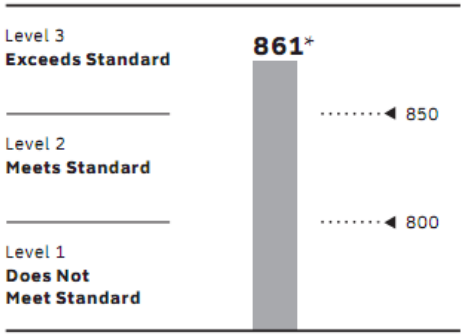
Class: **HOIT**
School: **NORTH SCHOOL**
System: **NORTH DISTRICT**

Lexile: 650L

CONTENT AREA	SCALE SCORE	PERFORMANCE LEVEL
Reading–GPS	**800**	**Meets**
English/Language Arts–GPS	**790**	**Does Not Meet**
Mathematics–GPS	**870**	**Exceeds**
Science–GPS	**870**	**Exceeds**
Social Studies–GPS	**796**	**Does Not Meet**

Subject | Score | Classification

Get to classification from score by using cut scores.



This student's score is **861**, which is in performance Level 3 and **exceeds the standard** for Reading.

Reading Domains	Number Correct	Number Possible
Literary Comprehension	19	24
Reading for Information	6	8
Reading Skills and Vocabulary Acquisition	7	8

Diagnostic Information

Breakdown content area into sub-domains

Sub-scores

Accessed from http://www.dekalb.k12.ga.us/instruction/testing/files/3DD48032E89A4A87944FD1D72AE878C1.pdf

What can DCMs do differently?

- Example from Georgia's federally mandated end-of-course assessments

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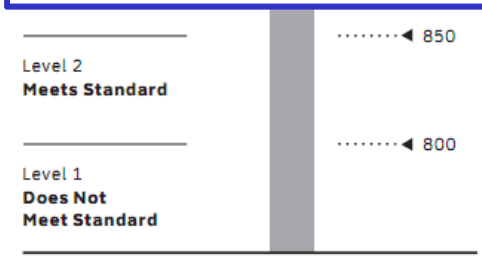

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Reading Domains	Number Correct	Number Possible
Literary Comprehension	19	24
Reading for Information	6	8
Reading Skills and Vocabulary Acquisition	7	8

DCMs can provide statistical probabilities an individual has mastered each sub-domain.

Breakdown content area into sub-domains

Sub-scores

Accessed from http://www.dekalb.k12.ga.us/instruction/testing/files/3DD48032E89A4A87944FD1D72AE878C1.pdf

Diagnostic Score Report

Diagnostic Scoring Report — Student Name: Daphne

Review Your Answers

Question	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Your Answer	✓	✓	✓	✓	a	c	✓	c	d	✓	✓	✓	c	✓	d	a	✓	b	a	a	d	c	b	a	c
Correct Answer	d	a	b	d	d	a	b	d	a	c	a	b	d	c	a	d	a	c	b	d	a	a	a	d	b
Difficulty	e	e	m	m	m	m	h	h	h	m	e	e	m	m	m	h	m	m	h	h	h	h	h	h	h

Score

You correctly answered 10 out of 25 questions.

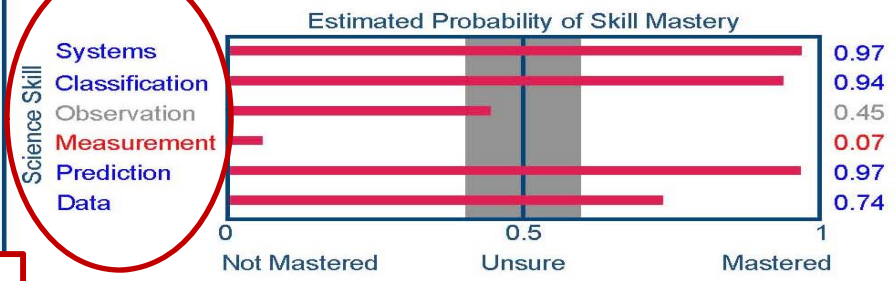
Easy: 4/4; Medium: 5/10; Hard: 1/11

Guide

✓ - Correct answer; o - Omitted answer

e - Easy; m - Medium; h - Hard

Improve Your Skills



Example Questions
3, 14, 2, 17, 19, 23, 9
3, 12, 13, 5, 2, 17, 18, 16, 24, 7
11, 15, 1, 8, 18
22, 20, 10, 11, 5, 6, 18, 25
4, 14, 20, 12, 5, 19, 9
22, 1, 19, 21

Skills or Sub-domains

Image from: Rupp, A. A., Templin, J., & Henson, R. (2010). *Diagnostic measurement: Theory, methods, and applications*. New York: Guilford.

DCM Conceptual Summary

- Diagnostic classification models (DCMs) are a set of statistical tools that provide diagnostic feedback
- Feedback is diagnostic in the sense that the **decision** itself–not just information to inform the decision–is given from the model
- No need for a two-stage approach of lining up and then cutting

DCM Conceptual Summary

- DCMs focus on **WHY** a respondent is not performing well as compared to only focusing on **WHO**
- The models define the chances of a correct response based on the respondent's attribute profile
- Many models have been created ranging in complexity
  - In Session #2 we discuss a general DCM
  - The general model subsumes all other latent-variable DCMs
- The model predicts how respondents will answer each item
  - Also allows for classification/diagnoses based on item responses

How do DCMs Produce Diagnoses?

- Diagnostic decisions come from comparing observed behaviors to two parts of the psychometric model:

1. Item/variable information (item parameters) — Measurement Model
   - How respondents with different diagnostic profiles perform on a set of test items
   - Helps determine which items are better at discriminating between respondents with differing diagnostic profiles
2. Respondent information pertaining to the base-rate or proportion of respondents with diagnoses in the population — Structural Model
   - Provides frequency of diagnosis (or diagnostic profile)
   - Helps validate the plausibility of the observed diagnostic profiles

WHY USE DCMS OVER TRADITIONAL APPROACH?

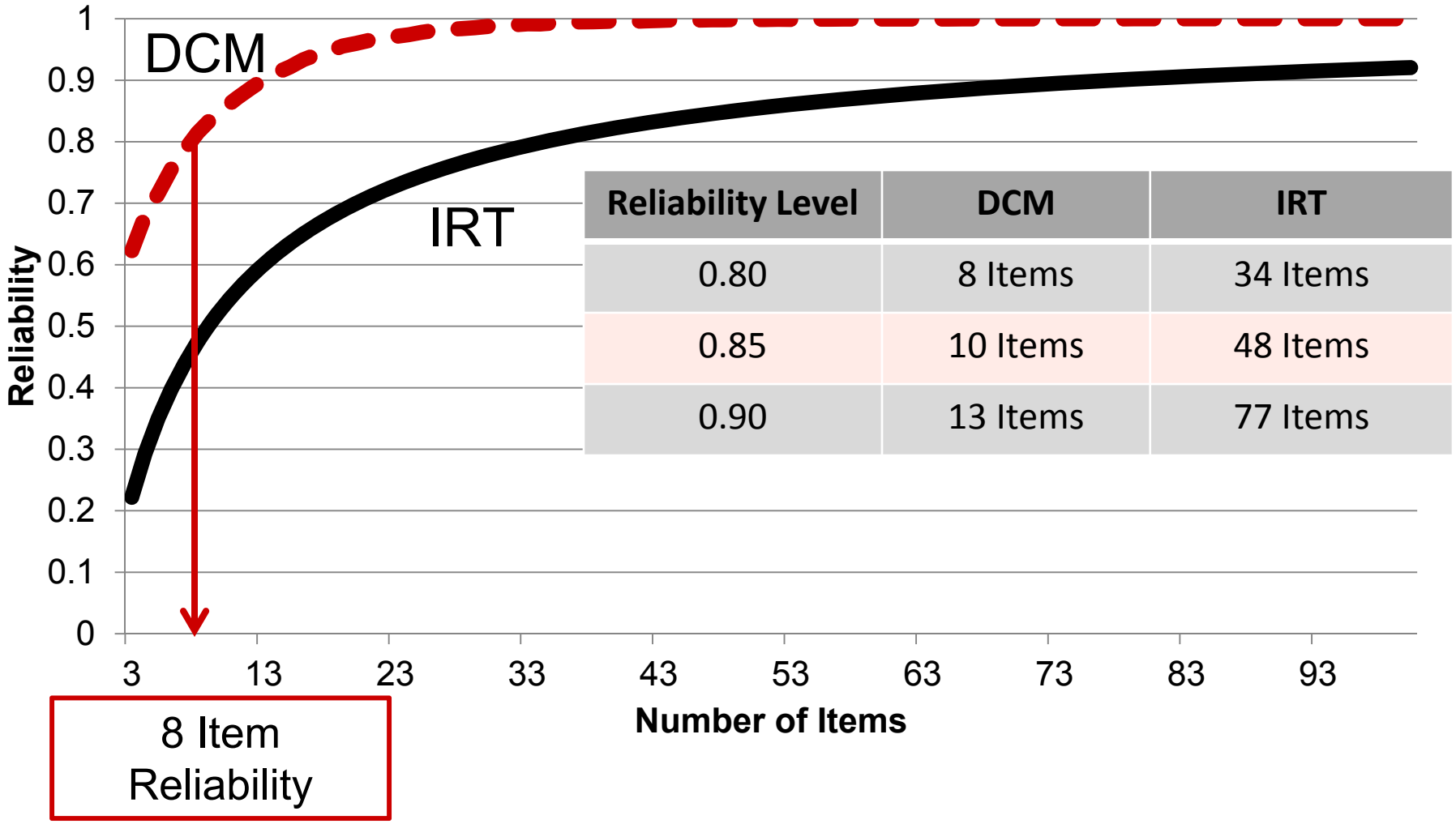
DCMs as an Alternative

- DCMs do not assign a single score

- Instead, a ***profile*** of ***mastered*** attributes is given to respondents
  - Multidimensional models

- DCMs provide respondents valuable information with fewer data demands
  - Higher reliability than comparable IRT/MIRT models
  - Complex item structures possible

Data Demands for Reliability (Unidimensional)

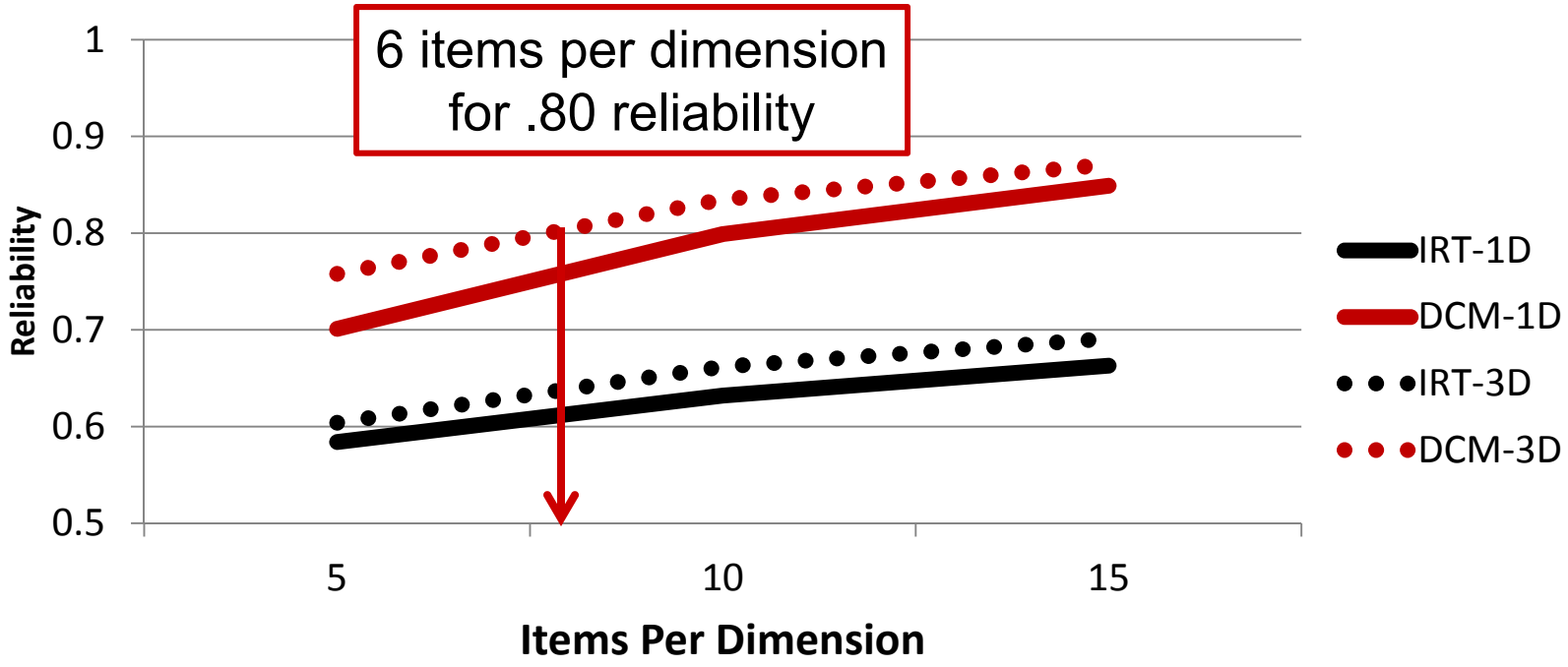


Reliability Level	DCM	IRT
0.80	8 Items	34 Items
0.85	10 Items	48 Items
0.90	13 Items	77 Items

Templin, J., & Bradshaw, L. (in press). Measuring the reliability of diagnostic classification model examinee estimates. *Journal of Classification.*

Data Demands for Reliability (Multidimensional)

- Can we measure multiple attributes reliably, too?

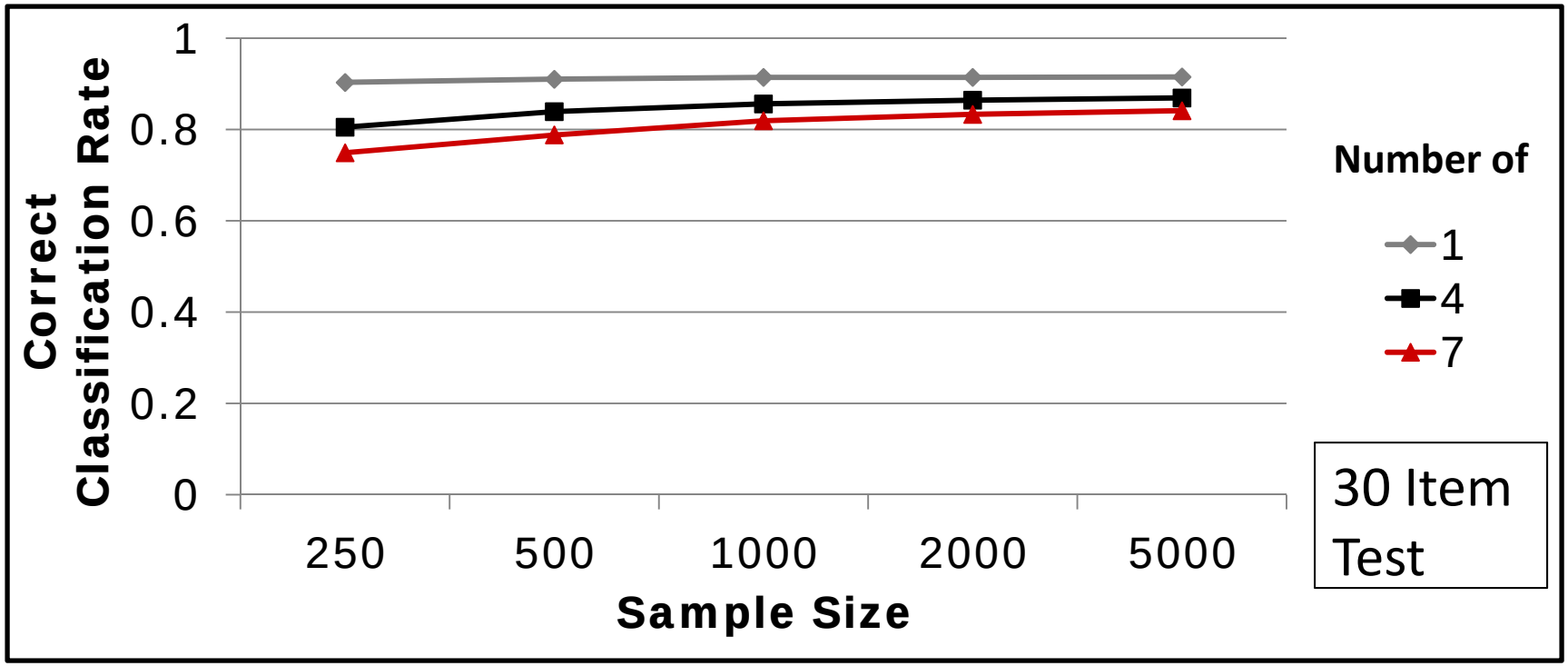


- 18 item diagnostic test → diagnose mastery of 3 attributes
- 34 item traditional test → scale unidimensional ability

Templin, J., & Bradshaw, L. (2014). Measuring the reliability of diagnostic classification model examinee estimates. *Journal of Classification.*

DCM Classification Accuracy

- What about the accuracy of the classification:
  - –As sample size decreases?
  - –As dimensionality increases?

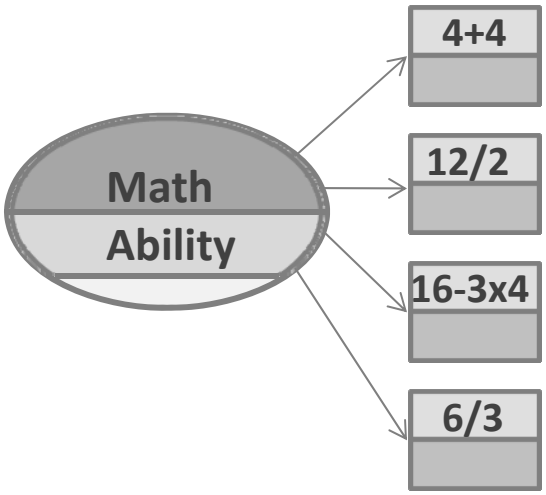


Bradshaw, L., & Cohen, A. (2010, May). Accuracy of multidimensional item response model parameters estimated under small sample sizes. In A. Izsák (Chair), *Using cognitive attributes to develop mathematics assessments, opportunities, and challenges.* Symposium conducted at the annual American Educational Research Association conference in Denver, CO.

Classifying into Multiple Groups

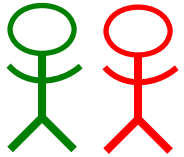
OTHER CONCEPTUAL EXAMPLES OF DCMS

Unidimensional, Multicategory DCMs



- Math ability is unidimensional
- Math ability is categorical, not continuous

- DCMs can be unidimensional and used for AYP-like classification purposes

	Advanced	Proficient	Basic
Math Ability			

- The classification is statistical (directly from the model)

What can DCMs do differently?

- Example from Georgia's federally mandated end-of-course assessments

Criterion-Referenced Competency Tests (CRCT) • Spring 2009

Name: **JOHNSON, JENNY A**
GTID: **5678123499**
Gender: **F**
Grade: **5**

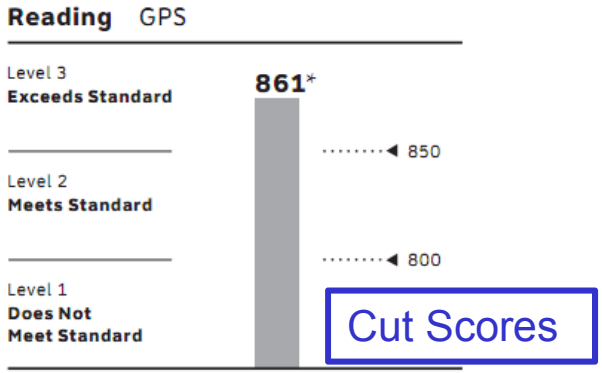
Class: **HOIT**
School: **NORTH SCHOOL**
System: **NORTH DISTRICT**

Lexile: 650L

CONTENT AREA	SCALE SCORE	PERFORMANCE LEVEL
Reading–GPS	**800**	**Meets**
English/Language Arts–GPS	**790**	**Does Not Meet**
Mathematics–GPS	**870**	**Exceeds**
Science–GPS	**870**	**Exceeds**
Social Studies–GPS	**796**	**Does Not Meet**

Subject | Score | Classification

DCMs can directly classify students into proficiency categories by assuming ability is unidimensional, but categorical.



This student's score is **861**, which is in performance Level 3 and **exceeds the standard** for Reading.

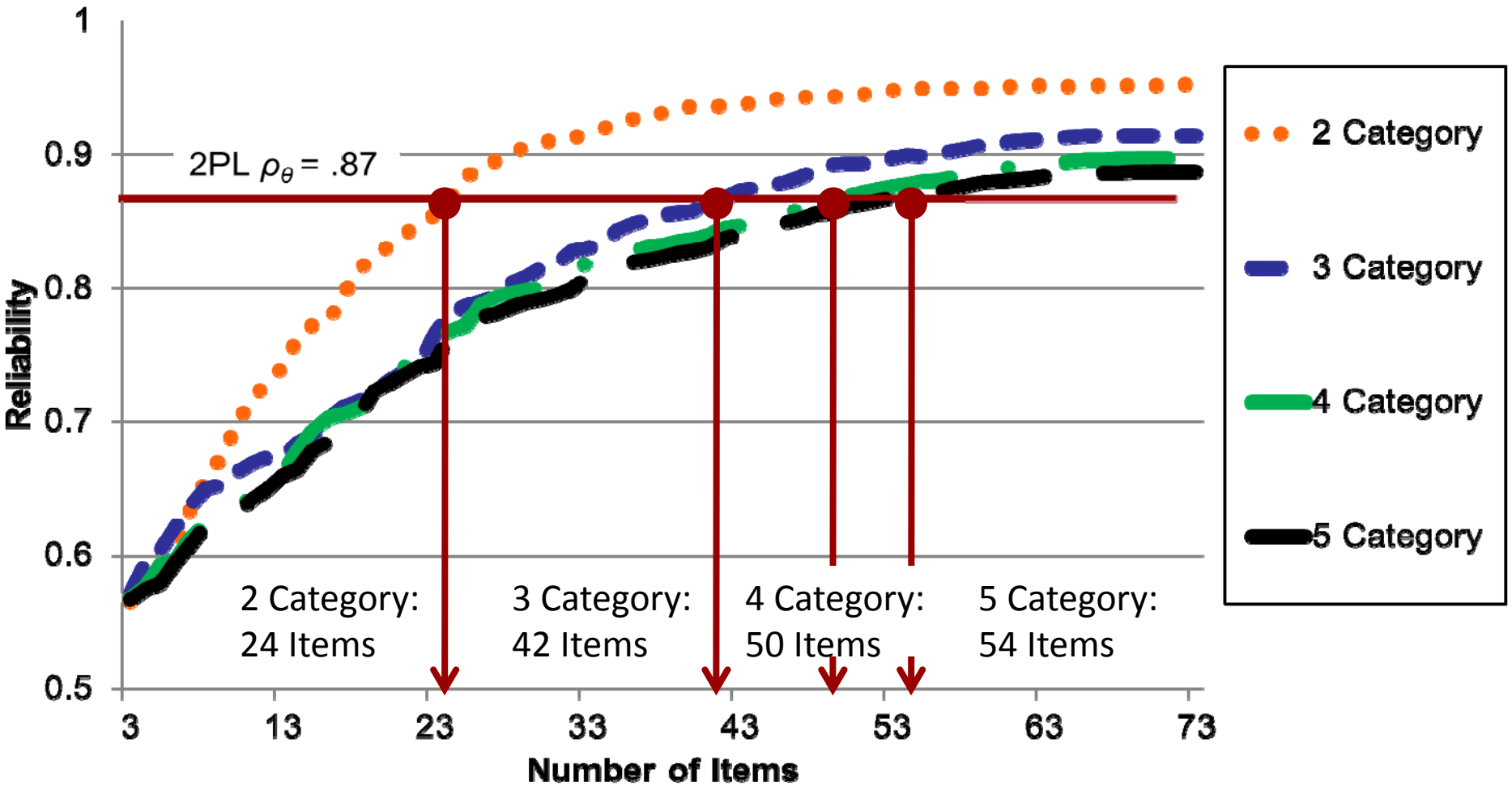
Reading Domains	Number Correct	Number Possible
Literary Comprehension	19	24
Reading for Information	6	8
Reading Skills and Vocabulary Acquisition	7	8

Breakdown content area into sub-domains

Sub-scores

Accessed from http://www.dekalb.k12.ga.us/instruction/testing/files/3DD48032E89A4A87944FD1D72AE878C1.pdf

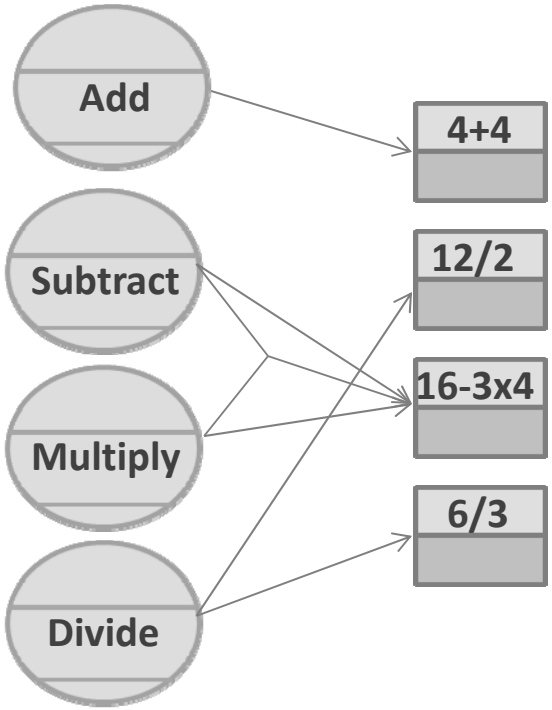
IRT vs DCM Reliability



- DCMs yield equal reliability with fewer items (which means shorter tests)

Templin, J., & Bradshaw, L. (2014). Measuring the reliability of diagnostic classification model examinee estimates. *Journal of Classification.*

Multicategory, Multidimensional DCMs



- DCMs can place students into more than 2 groups

	Advanced	Proficient	Basic
Add			
Subtract			
Multiply			
Divide			

Attributes are still categorical, but now have 3 categories instead of 2

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IMPLICATIONS FOR LARGE SCALE TESTING PROGRAMS

DCM Characteristics

- As mentioned previously, DCMs provide a higher level of reliability for their estimates than comparable IRT or CTT models (Templin & Bradshaw, 2013)
  - It is easier to place a respondent into one of two groups (mastery or non-mastery) than to locate them on a scale

- Such characteristics allow DCMs to potentially change how large scale testing is conducted
  - Most EOC-type tests are for classification
    - Proficiency standards
  - DCMs provide direct link to classification
    - And direct access to standards

Ramifications for Use of DCMs

- Reliable measurement of multiple dimensions is possible
  - Multidimensional proficiency standards
    - Respondents must demonstrate proficiency on multiple areas to be considered proficient for an overall content domain
  - "Teaching to the test" would therefore represent covering more curricular content to best prepare respondents
- Shorter unidimensional tests
  - Unidimensional DCM application to empirical data:
    - Test needed only 24 items to have same reliability as IRT with 73 items

Ramifications for Use of DCMs: Formative Assessment

- Classroom appropriate test lengths
  - Teaching and testing time is limited
- Multivariate feedback
  - Strengths and weaknesses profiles
- No scores
  - Argued as a key element of effective formative testing in research

The Paradox of DCMs

- DCMs are often pitched as models that allow for measurement of "fine-grained" skills (e.g., Rupp & Templin, 2008)

- Paradox of DCMs:
  - Sacrifice fine-grained measurement of a latent trait for only several categories
  - Increased capacity to measure ability multidimensionally

When Are DCMs Appropriate?

- Which situations lend themselves more naturally to such diagnosis?
  - The *purpose* of the diagnostic assessment matters most
  - DCMs provide classifications directly
    - Optimally used when tests are used for classification
      - EOC Tests
      - Licensure/certification
      - Clinical screening
      - College entrance
      - Placement tests
  - DCMs *can* be used as coarse approximations to continuous latent variable models
    - i.e., EOC example (2-5 category levels shown)

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BENEFITS OF DCMS OVER TRADITIONAL CLASSIFICATION METHODS

Previous Methods for Classification

- Making diagnoses on the basis of test responses is not a new concept
  - Classical test theory
  - Item response theory
  - Factor analysis

- Process is a two-stage procedure
  1. Scale respondents
  2. Find appropriate cut-scores

- Classify respondents based on cut-scores

Problems with the Two-Stage Approach

- The two-stage procedure allows for multiple sources of error to affect the results

1. The latent variable scores themselves: estimation error
   - Uncertainty is typically not accounted for in the subsequent classification of respondents (i.e., standard errors)
   - The classification of respondents at different locations on the score continuum with multiple cut-scores is differentially precise
     - Uncertainty of the latent variable scores varies as a function of the location of the score

Problems with the Two-Stage Approach

2. Latent variable assumptions: that latent variable scores follow a continuous, typically normal, distribution
   - Estimates reflect the assumed distribution
   - Can introduce errors if the assumption is incorrect

3. Cut-score determination
   - Standard setting is imprecise when used with general abilities
     - Standard setting methods can be directed to item performance
   - Some theoretical justification needs to be provided for such a cut-off

Why are DCMs Better for Classification?

- The need for a two-stage procedure to set cut-scores for classification is eliminated when DCMs are used
  - Reduces classification error
- Quantifies and models the measurement error of the observable variables
  - Controlling for measurement error when producing the diagnosis
- DCMs have a natural and direct mechanism for incorporating base-rate information into the analysis
  - No direct way to do so objectively in two-stage procedures
- Item parameters provide information as to the diagnostic quality of each item
  - Not directly estimable in two-stage approaches
  - Can be used to build tests that optimally separate respondents

Session 1: Conceptual Foundations of Diagnostic Measurement

CONCLUDING REMARKS

Session 1 – Take-home Points

- DCMs provide direct link between diagnosis and behavior
  - Provide diagnostic classifications directly
  - Diagnoses set by psychometric model parameters
- DCMs are effective if classification is the ultimate purpose
  - Reduce error by removing judgments necessary in two-stage approach
- DCMs can be used in many contexts
  - Can be used to create highly informative tests
  - Can be used to measure multiple dimensions