Reconceptualizing Items: *From Clones and Automatic Item Generation to Task Model Families*

Richard M. Luecht, Ph.D., UNC-G

Matthew J. Burke, Ph.D., ABIM

Outline of the Talk

- Rationale
- Reconceptualizing “items” and test content
- Item models and automatic item generation (AIG): mechanisms for mass producing items
- Cognitive task models and “item families”: an engineering approach to scale and test development
- Quality control (QC) for item families

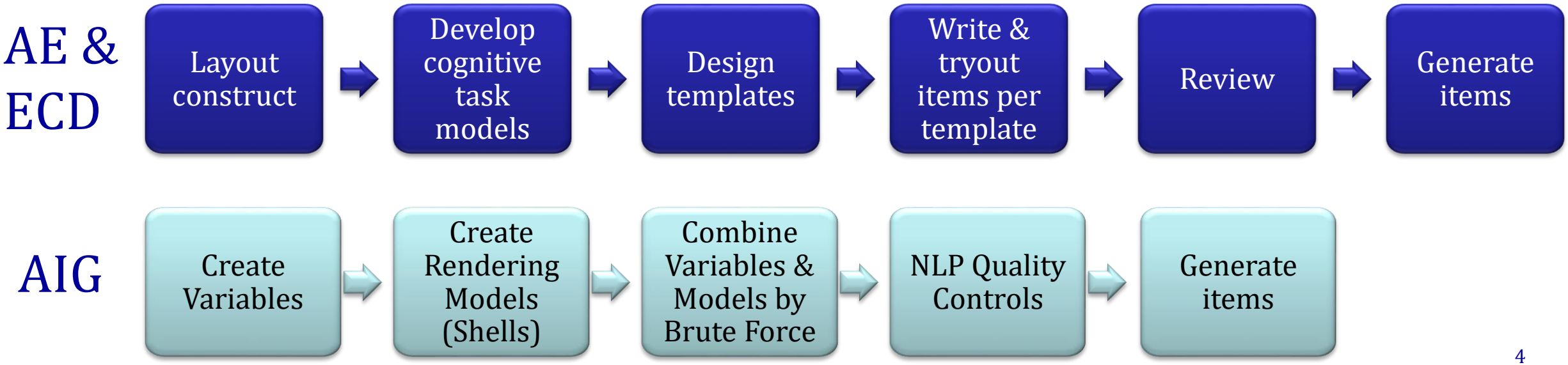
Why Use Automated Item Generation and Principled Item Design Technologies?

"*The demand for large numbers of items is challenging to satisfy because the traditional approach to test development uses the item as the fundamental unit of currency. That is, each item is individually hand-crafted—written, reviewed, revised, edited, entered into a computer, and calibrated—as if no other like it had ever been created before.*"

Drasgow, Luecht & Bennett, *Educational Measurement*, 4th Edition, p. 473

So…Item and Test Design are Changing

- Traditionally, the quality of test item generation has been dependent on the experience and interpretation of content specifications by item writers (Schmeiser & Welch, 2006)
- Principled item design (Bennett, 2001; Irvine, 2002) is rapidly evolving from theory to practical implementation



The Evolution of “Items”

Item Writing/Editing as a *Craft?*

Item Shells

<Patient.article><Patient.description.age>
<Patient.description.occupation>
"***comes to***" <Setting.description> "***complaining of***"
<Patient.ailment.symptom1> <Patient.ailment.symptom1.duration>
<Patient.ailment.symptom2> <Patient.ailment.symptom2.duration>
<Patient.history.activity.recent>
<Patient.physicalexam.temp=# C, (convert(C,F))>
<Patient.physicalexam.pulse=#/min>
<Patient.physicalexam.respiration=#/min>
<Patient.physicalexam.bp=#1/#2>
<Patient.physicalexam.symptom1>
<Patient.physicalexam.symptom2> ***"What is the most likely cause of"***
<Patient.ailment.prime_symptom> "?"

Different Item Generation Perspectives

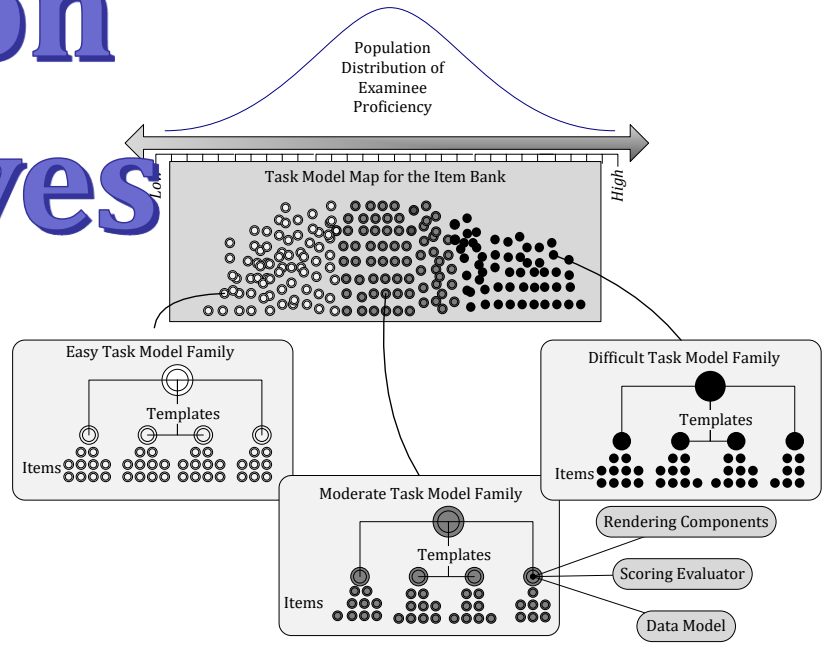
N-Layered AIG & Mass Item Production Models

Solve (low complexity function | several number of operations. explicit application. three unique variable)

	Item Model Variables
Stem	Simplify the following in equation: $\text{Log}(10^{I1^{I2}} + 10^{I3} - 10^{I4})$
Elements	I1 Value Range: 2 – 5 by 1 I2 Value Range: 2 – 3 by 1 I3 Value Range: 2 – 5 by 1 I4 Value Range: 2 – 5 by 1

Task Model → Item Template

Task Model Families



What is an "item"?

Questions 10 – 12

*Choose the appropriate letters **A**, **B**, **C** or **D**.*

Write your answers in boxes 10-12 on your answer sheet.

10 Research completed in 1982 found that in the United St

- **A** reduced the productivity of farmland by 2
- **B** was almost as severe as in India and Chi
- **C** was causing significant damage to 20 pe
- **D** could be reduced by converting cultivate

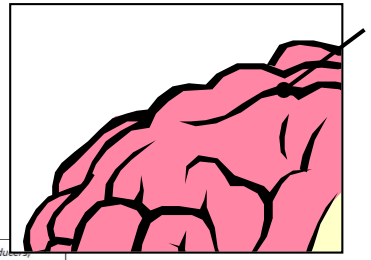
11 By the mid-1980s, farmers in Denmark

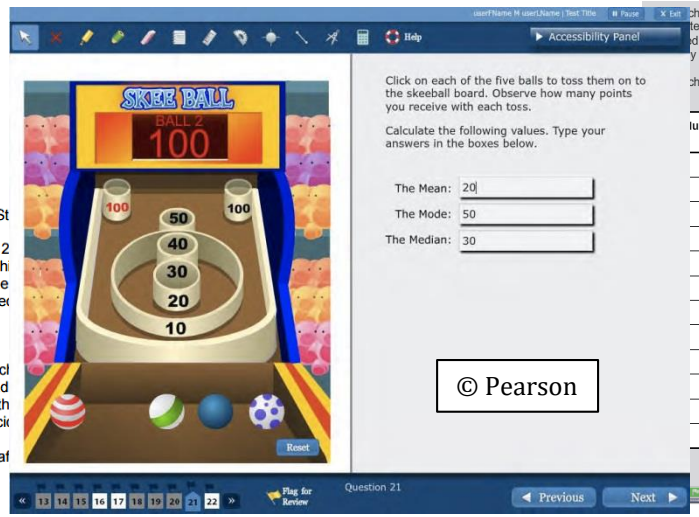
- **A** used 50 per cent less fertiliser than Dutcl
- **B** used twice as much fertiliser as they had
- **C** applied fertiliser much more frequently th
- **D** more than doubled the amount of pesticic

12 Which one of the following increased in New Zealand af

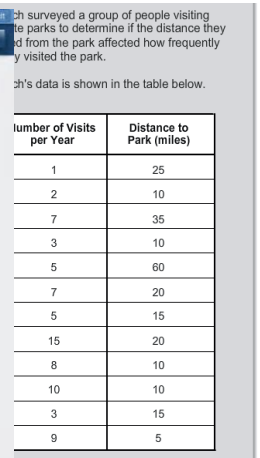
- **A** farm incomes
- **B** use of fertiliser
- **C** over-stocking
- **D** farm diversification

Where is the in the cerebral cortex's parietal lobe? (*Click on the appropriate area of the picture, below*)

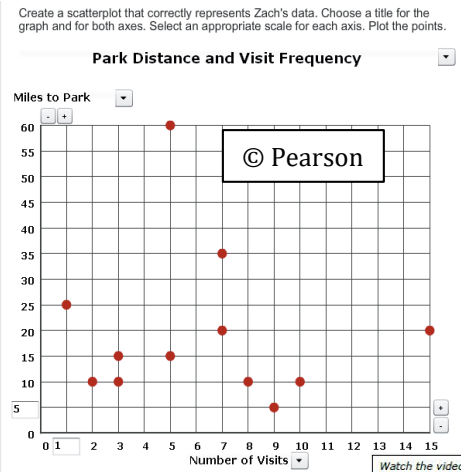




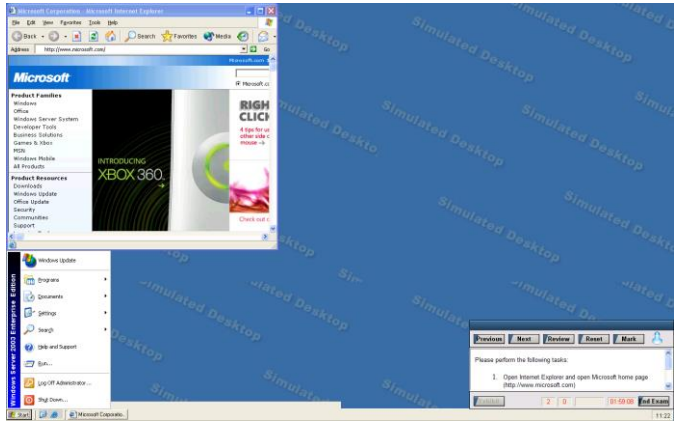
© Pearson

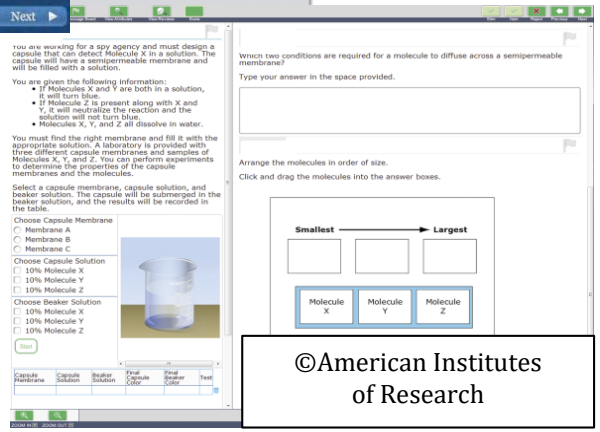


Number of Visits per Year	Distance to Park (miles)
1	25
2	10
7	35
3	10
5	60
7	20
5	15
15	20
8	10
10	10
3	15
9	5

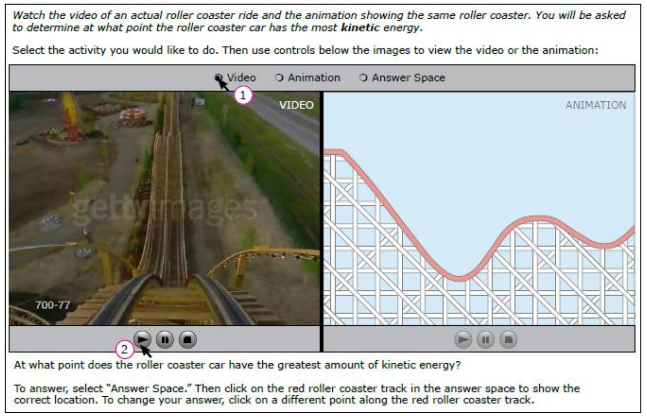


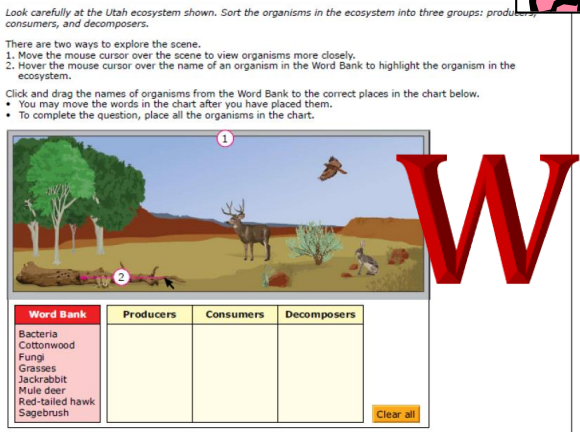
© Pearson

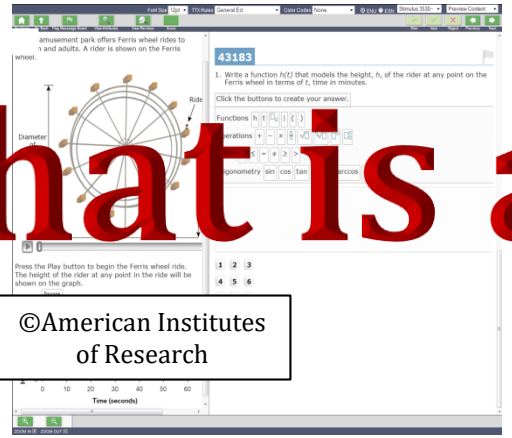




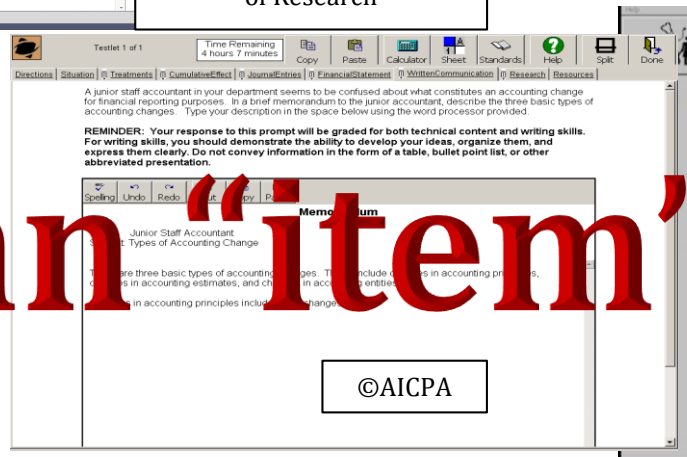
©American Institutes of Research



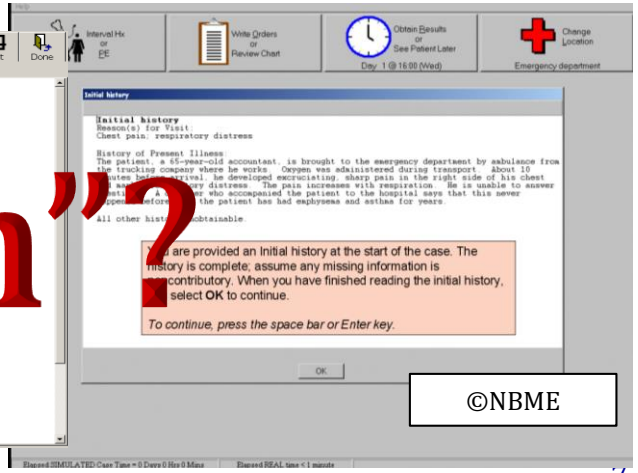




©American Institutes of Research



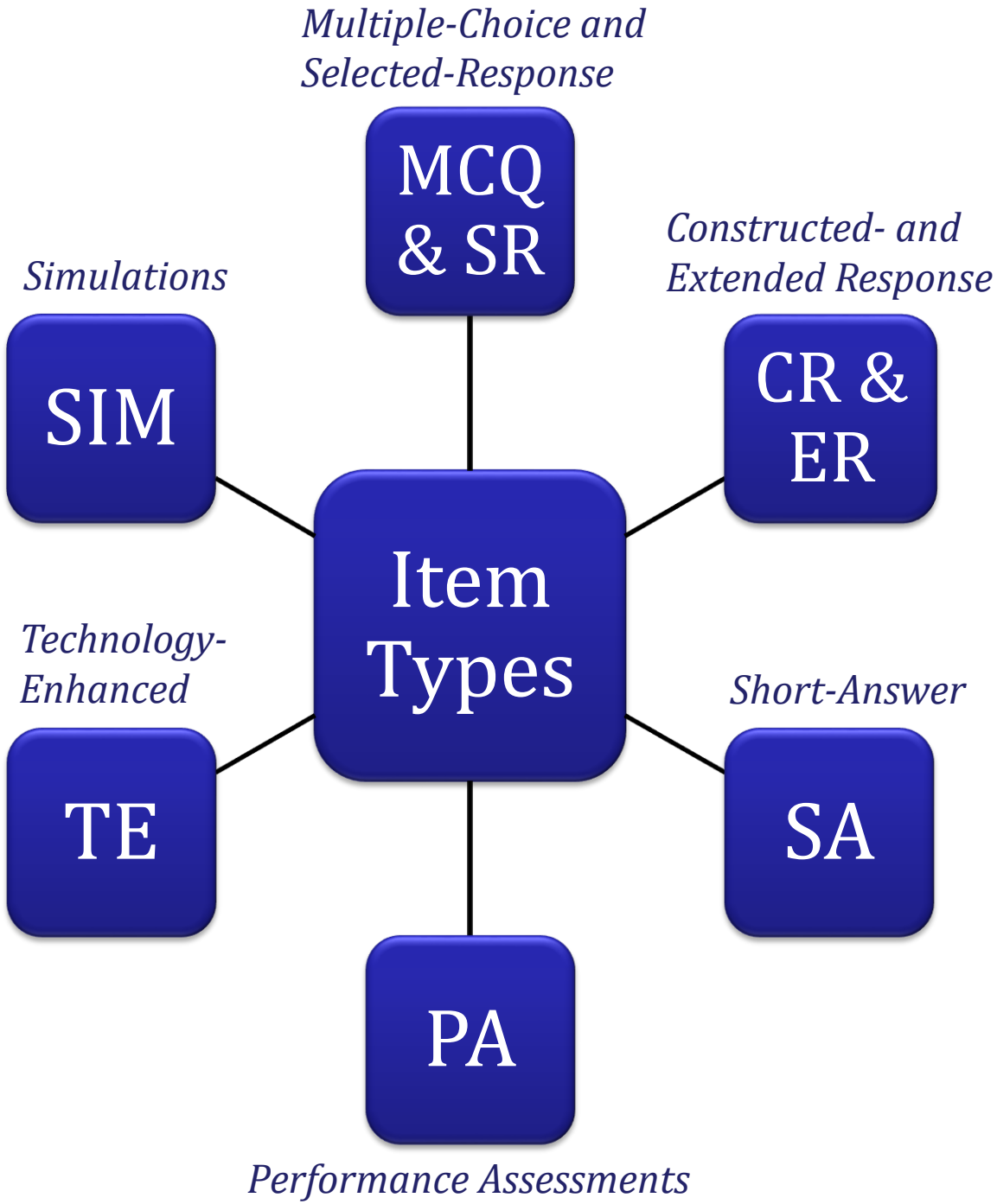
©AICPA



©NBME

Complications of *Item Types*

- Stimuli, prompts and problem instructions
- Exhibits
- Auxiliary tools/resources
- Response capturing
- Response data
- Scoring evaluators



Unconstrained

Constrained

Actual Performance

Work Samples

Essays, PBAs, Free-Response (FR) and CR Items

Short-Answer (SA) Items

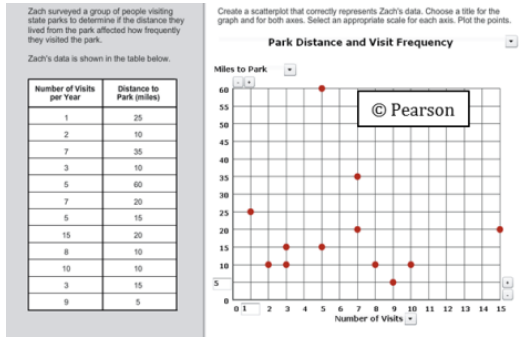
Interactive Simulations

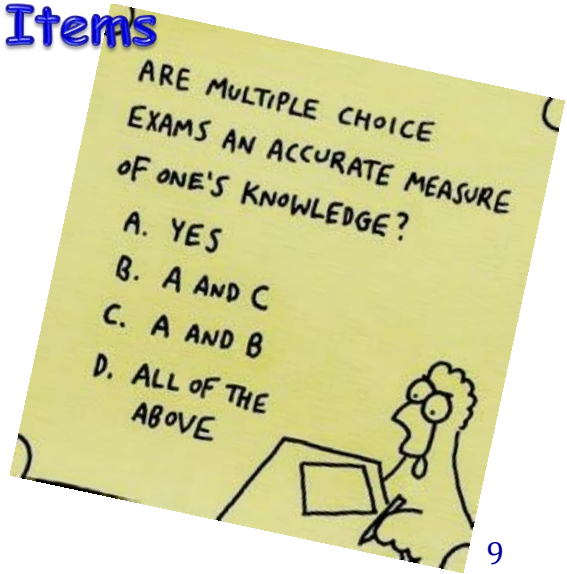
Technology-Enhanced (TE) Items

Long-Option List Selected-Response Items (Incl. "Pick-N's")

True-False or Binary Choice Items

Multiple-Choice (MC) Items





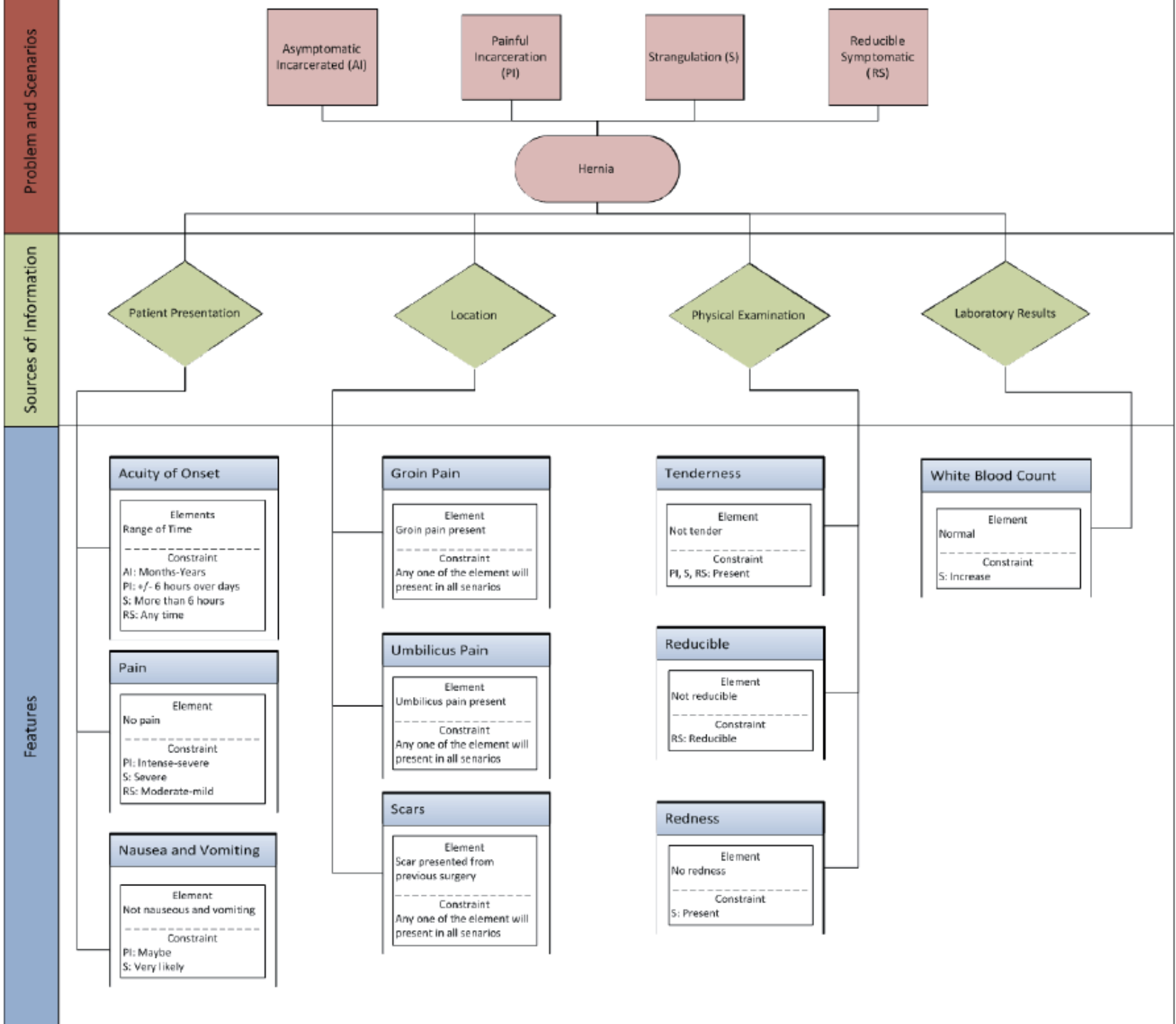
Automatic Item Generation (AIG) for Enhanced Multiple-Choice Item Production

AIG in Three Steps*

- The content required for the generated items is identified by test development specialists and defined as a *cognitive model*
- An *item model* is developed by the test development specialists to specify where content is placed in each generated item
- In Step #3, computer-based algorithms are used to place the content specified in Step #1 into the item model developed in Step #2

* Gierl, Lai & Turner (2012). Using automatic item generation to create multiple- choice test items. *Medical Education, 46*,757–765

Step #1. Documenting the Item Content



Step #2. Generating an Item Model

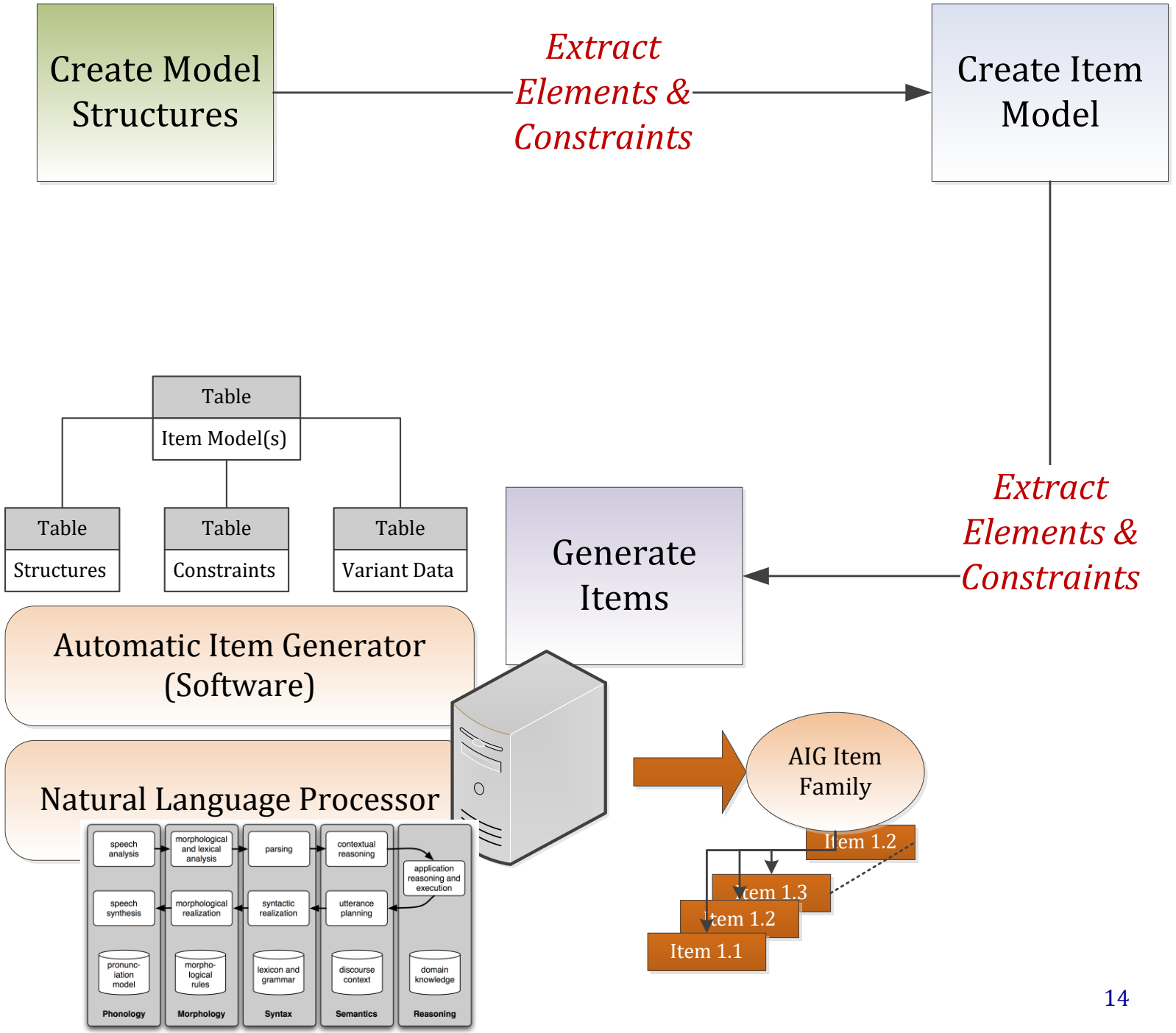
A 25-year-old man presented with a mass in the left groin. It occurred suddenly 2 hours ago while lifting a piano. On examination, the mass is firm and located in the left groin and lab work came back with normal results. Which of the following is the next best step?

A [AGE]-year-old [GENDER] presented with a mass [PAIN] in [LOCATION]. It occurred [ACUITYOFONSET]. On examination, the mass is [PHYSICALFINDINGS] and lab work came back with [WBC]. Which of the following is the next best step?

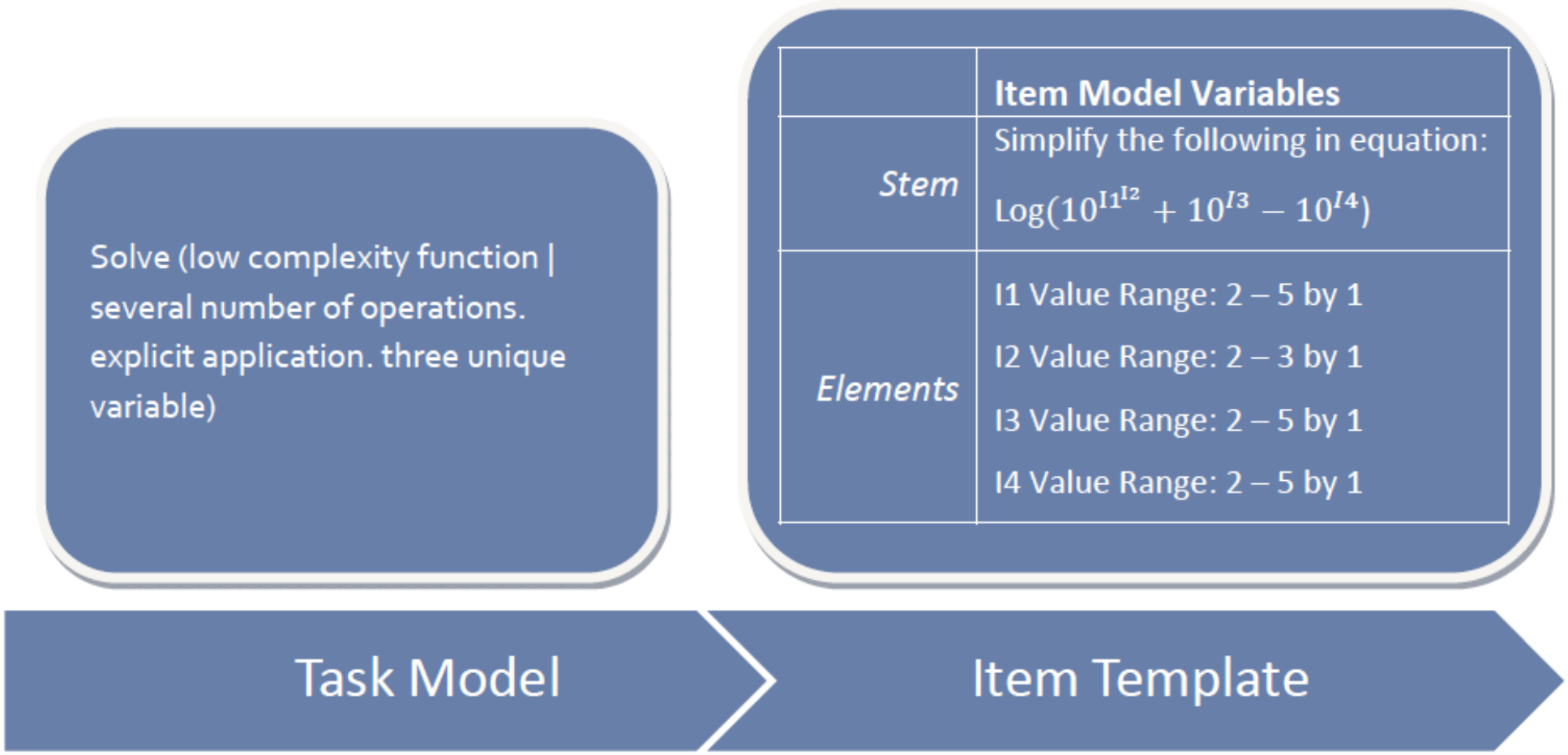
[AGE] (Integer): From 25.0 to 60.0, by 5.0
[GENDER] (String): 1: man 2: woman
[PAIN] (String): 1: 2: and intense pain 3: and severe pain 4: and mild pain
[LOCATION] (String): 1: the left groin 2: right groin 3: the umbilicus 4: an area near a recent surgery
[ACUITYOFONSET] (String): 1: a few months ago 2: a few hours ago 3: a few days ago 4: a few days ago after moving a piano
[PHYSICALFINDINGS] (String): 1: protruding but with no pain 2: tender 3: tender and exhibiting redness 4: tender and reducible
[WBC] (String): 1: normal results 2: normal results 3: elevated white blood cell count 4: normal results

Contextual features: exploratory surgery; reduction of mass; hernia repair; ice applied to mass

Step #3: Submitting Template(s), Elements and Constraints to an *Item Generator*



Sample AE Math Task Model and Templates



Lai, H.; Gierl, M. & Alves, C. (2010). *Generating Items under the AE Framework*. Invited symposium paper at the Annual Meeting of NCME, Denver

AE Item Production

	Range of Elements					
Item Template #	Element 1	Element 2	Element 3	Element 4	Element 5	Number of items
Mathematics						
1	5	8	9			355
2	2	3	3			18
3	8	6	4	4		762
4	20	9	33			5940
5	3	3	3			27
6	3	2	2			12
7	8					8
8	4	4	4	4	4	896
9	5	3	13	11		2132
10	4	2	4	4		128

Lai, H.; Gierl, M. & Alves, C. (2010). *Generating Items under the AE Framework*. Invited symposium paper at the Annual Meeting of NCME, Denver

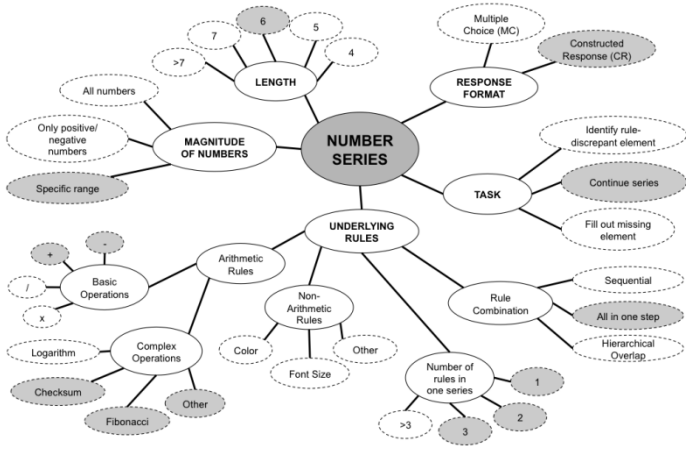
Multiple-Language AIG*

- Human translations add expense and error on top of an already expensive process of artfully crafted items
- Translated English-generated medical licensing examination multiple-choice items into Canadian French and Chinese by adding a “language layer” to the item models
- Still partly a work in progress since the “art” of translation is seldom exact, given the nuances of language
  - Sin embargo... el "arte" de la traducción es raramente exacto
  - However... the 'art' of the translation is rarely accurate

* Gierl, Lai & Turner (2012). Medical Education. Gierl, Fung, Lai & Zheng (2013). National Council on Measurement in Education Symposium Paper.

Rule-Based AIG for Number Series Items (J.P. Bertling, NCME, 2013)

- AIG model premise: *number series problems* are a convenient format to measure some aspects of numerical reasoning (application of rule-based induction) and are amenable to algorithmic item design
- There is a *mature* "task model" for number series problems



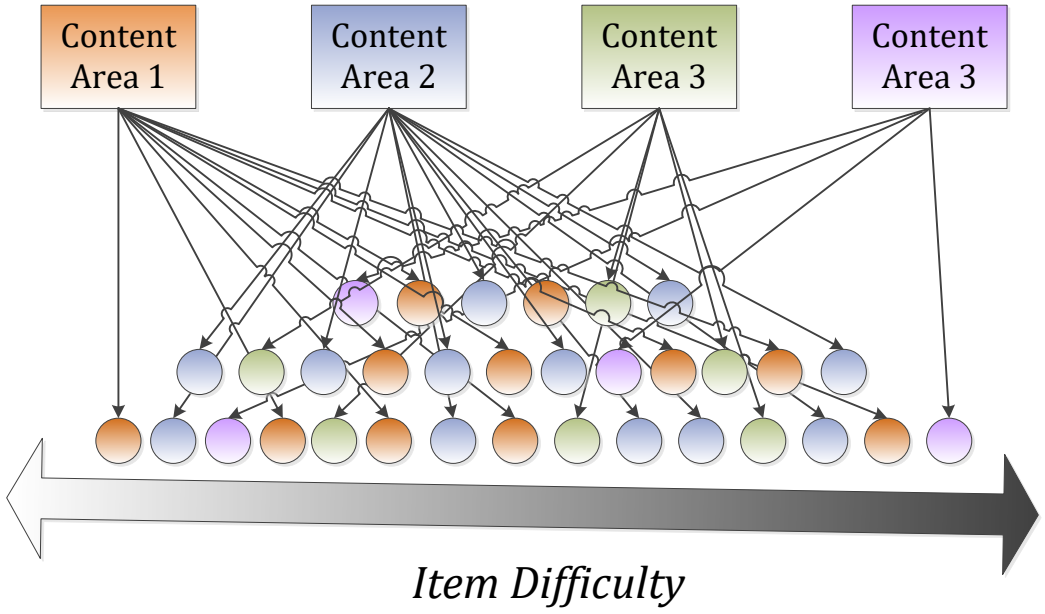
Standards for AIG (Embretson & Poggio, NCME, 2013)

- AIG →less human involvement ($$$)
- AIG without STRONG quality controls and evaluation criteria is not fruitful
- Standards that depend on projected use and quality of evidence
  - Quality of item content
  - Predictability of item parameters
  - Impact of item predictability on score reliability
- How much should traditional "content blueprints" drive these standards?

An Cognitive-Engineering Approach to Test Development

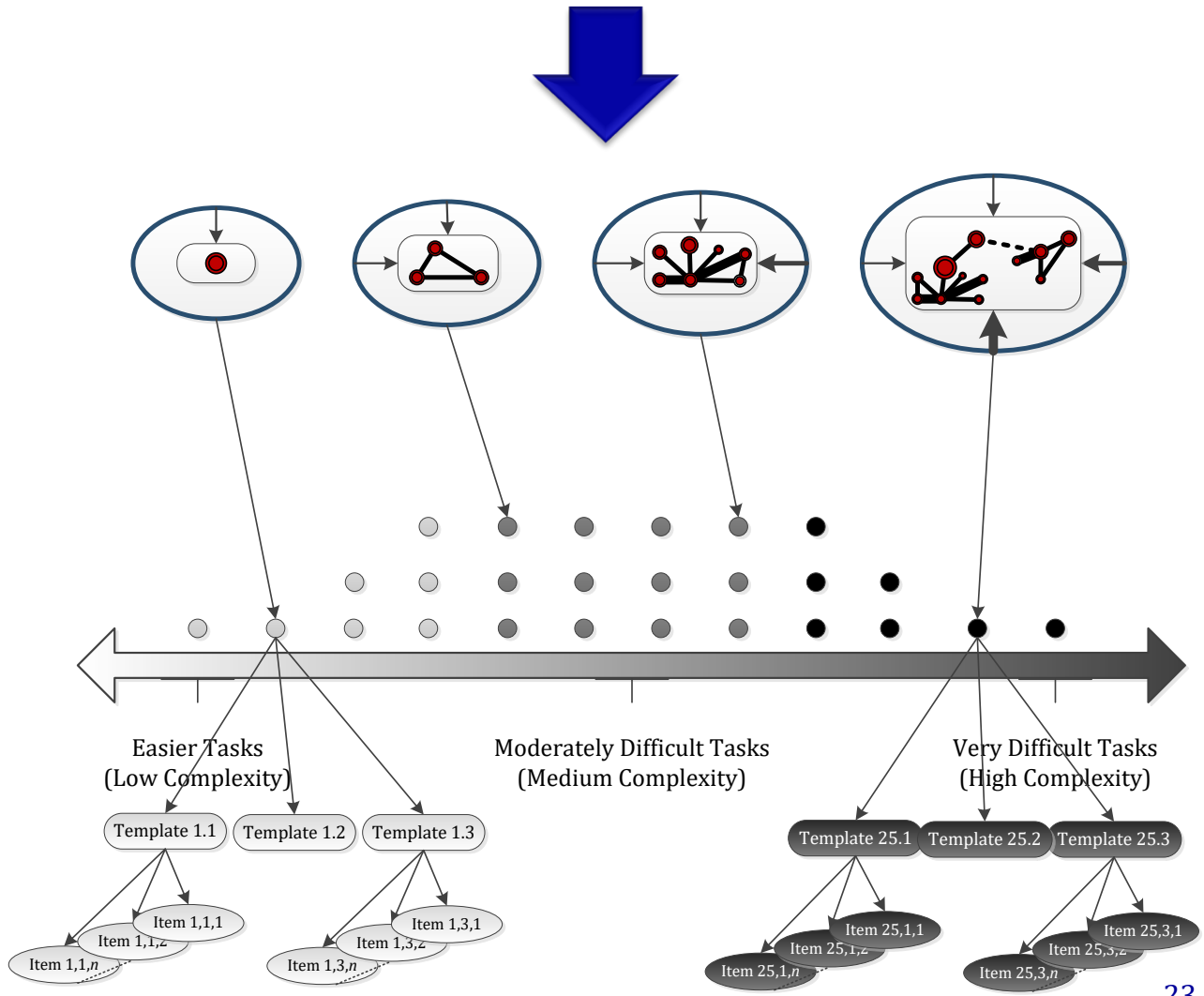
Assessment Engineering (AE) **combines the *scalability and replicability of AIG* (i.e., as an item-production mechanism) with *empirically verified cognitive task modeling and strong statistical quality controls*...all required for isomorphism within ITEM FAMILIES**

From a task modeling perspective, content will NOT necessarily be the same across the SCALE because task models differ in complexity

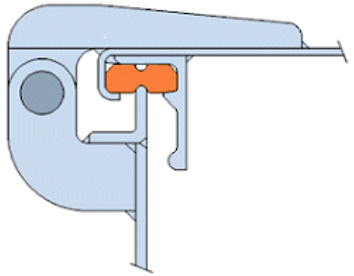


Traditional Item Writing and Test Assembly

Items as Part of a Task Model Family



The Need for Engineering Principles Like Robust *Composability* to Item-Template Design

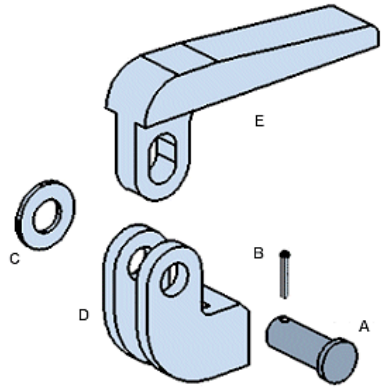


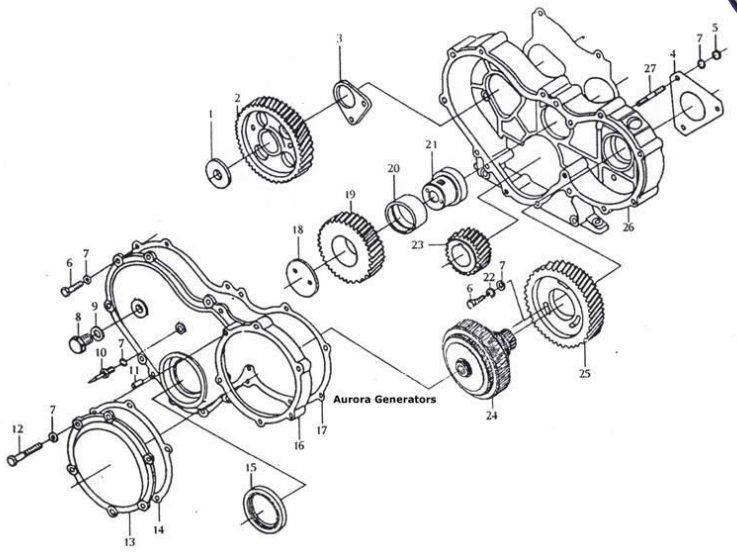
Standardized Components

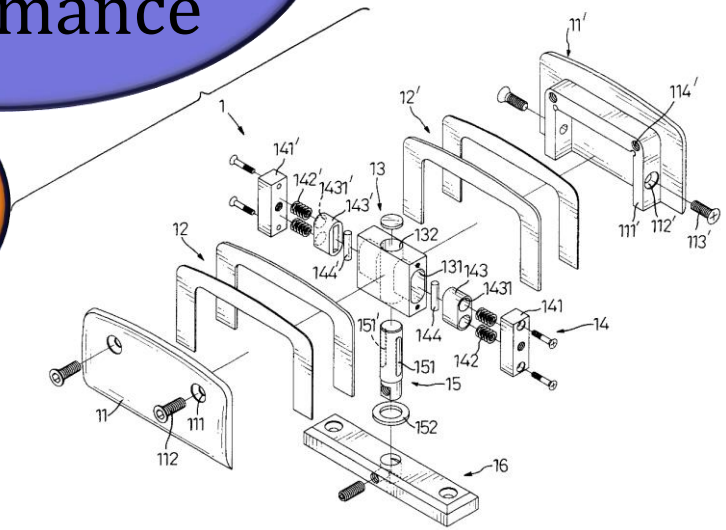
Scalable & Replicable Designs

Stable Cross-Platform Performance

Consistent Data





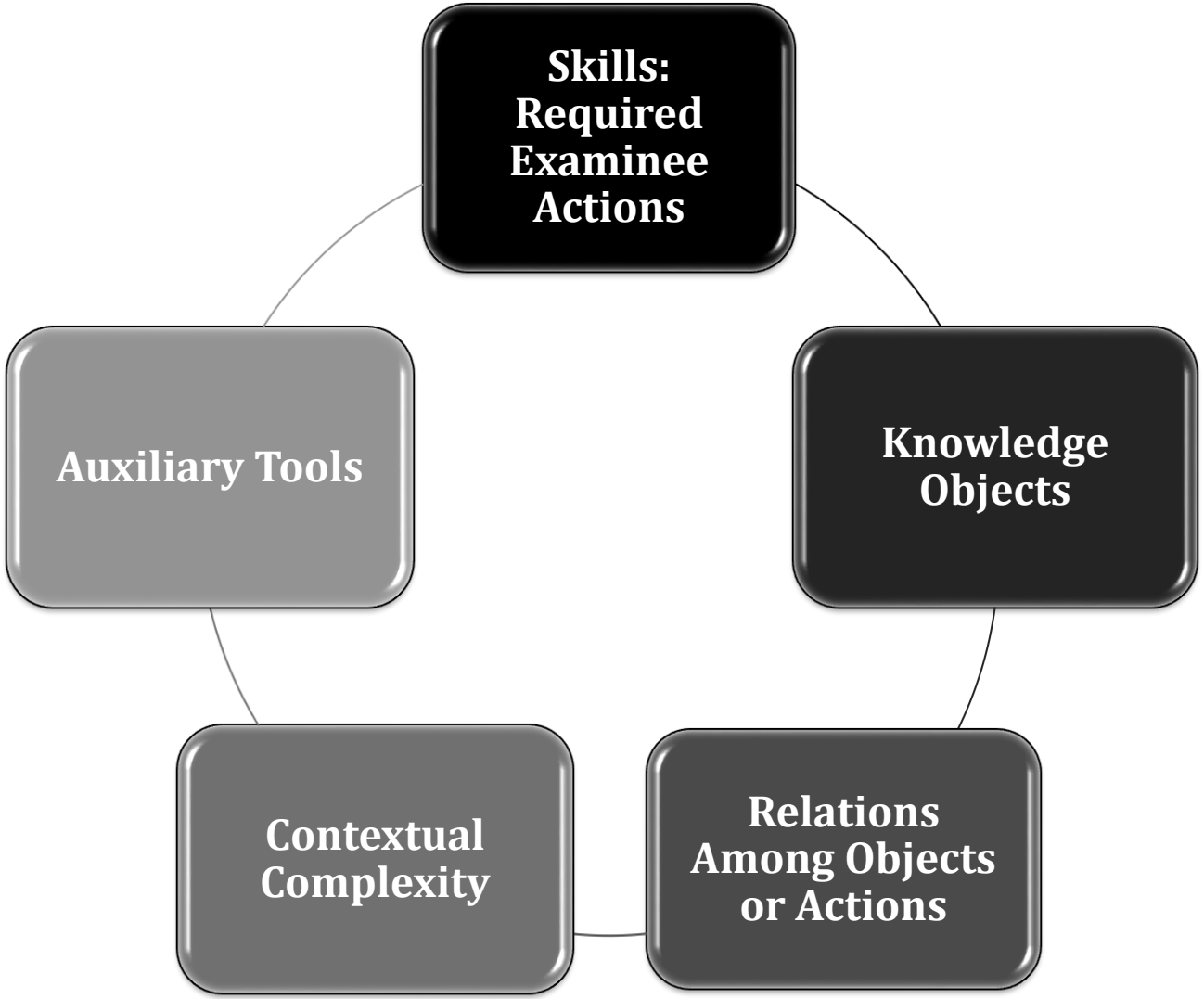


Cognitive Task Modeling

- **Task Model Grammars (TMGs)** are *domain-specific languages* that describe the intended cognitive complexity design features for families of assessment tasks—the **Task Models**
  - Content and declarative knowledge components
  - Procedural skills needed
  - Tools, resources
  - Contextual conditions
- **Task Model Maps (TMMs)** provide a distribution of Task Models on a scale

Cognitive Skill-Based Task Models

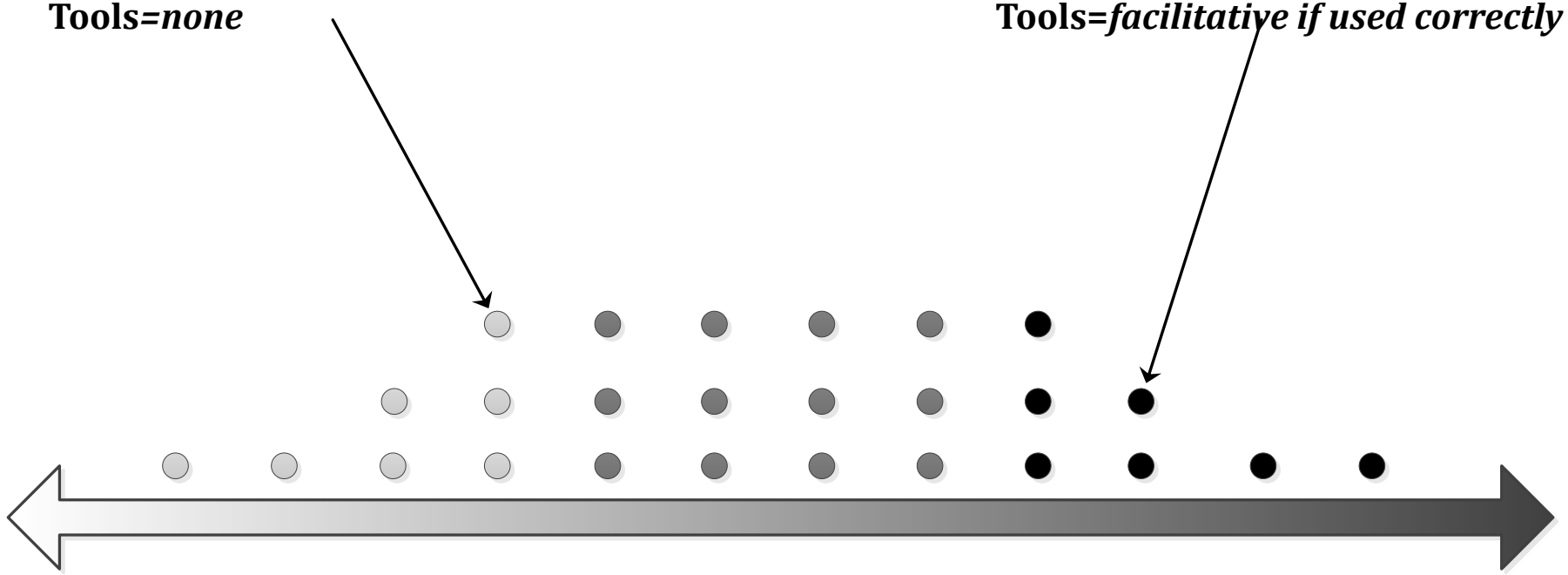
$$action_2\left[action_1\left(is.related\left(object_1, object_2\right), object_3 \mid context, aux.tools\right)\right]$$



Task Model Mapping: ***Locating Intended Challenges*** to Support Evidence-Based Claims

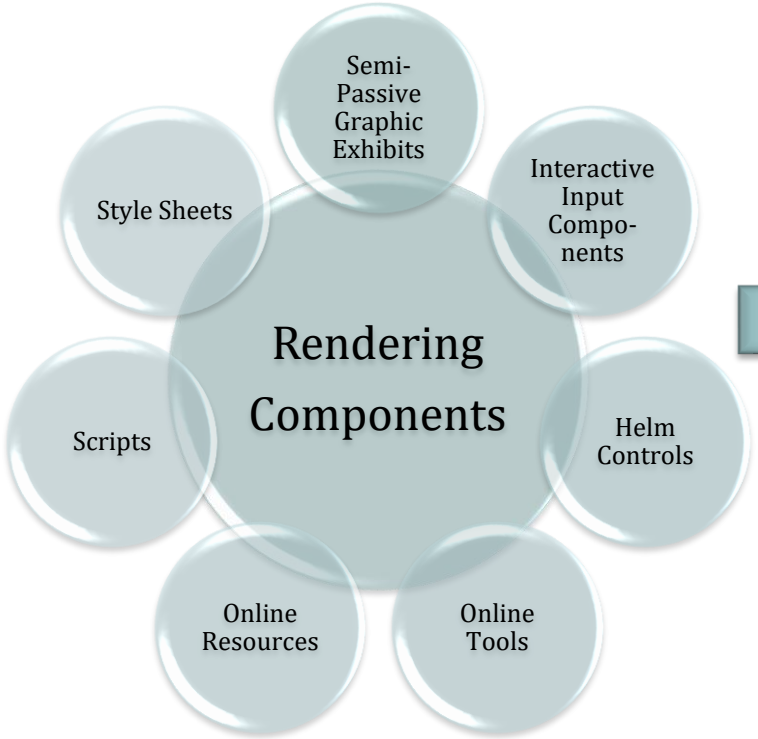
Skill=*identify*
Objects = *one, simple concept*
Relations=*none*
Context=*match word → definition*
Tools=*none*

Skills=*identify, compare, evaluate*
Objects = *3-4 complex properties*
Relations=*hierarchical (3 levels)*
Context=*complex text, dense info.*
Tools=*facilitative if used correctly*



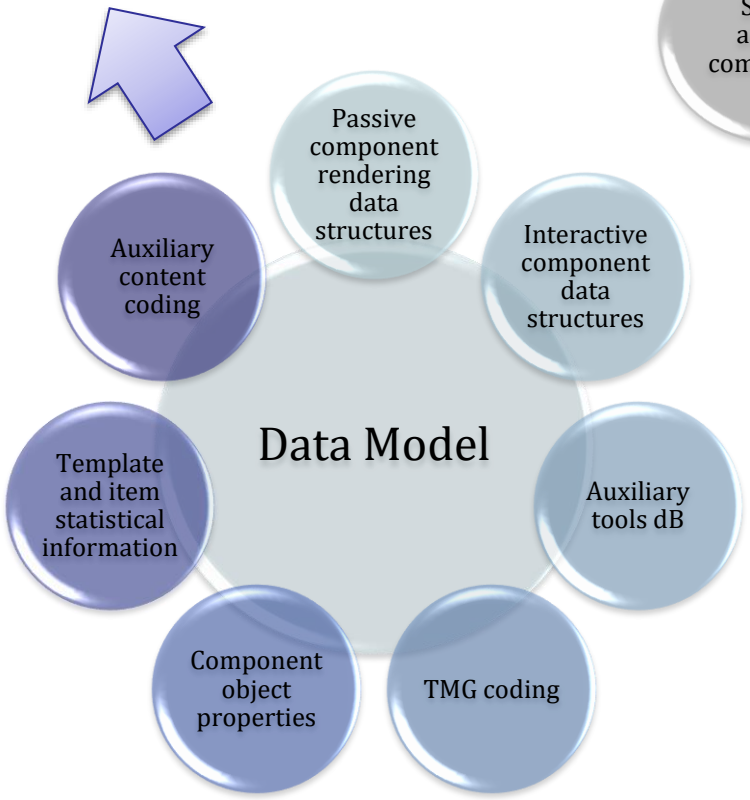
Types of Task Models

- ***Fixed-specification*** task models
  - Number of task models = no. of test items
  - Each task model is essential
- ***Domain-sampled*** task models
  - Multiple task models per location
  - Task models are considered exchangeable at a particular location
- ***Self-adaptive performance*** task models
  - Template components are manipulated to change the information (location)
  - Optimal reconfiguration of components



Hundreds of "item types" may be possible

Open-Ended Template Architecture for ANY Item Type



A Prototype Item for the CCSS H.S. Statistics & Probability Standard

Calculate expected values and use them to solve problems: (S-MD.3.) Develop a probability distribution for a random variable defined for a sample space in which **theoretical probabilities** can be calculated; find the expected value. *(CCSS Initiatives Project,* www.corestandards.org/the-standards/mathematics/hs-statistics-and-probability/)

A test has five multiple-choice questions scored correct/incorrect. Each question has four possible options. What will be the expected number-correct score for students who guess the answers to all five of the questions?

A. 0.25
B. 0.80
C. 1.25
D. 3.75
E. 5.00

A Possible Set of TMG Specifications for Our Statistics *E*(*y*) Standard

Calculate expected values and use them to solve problems: (S-MD.3.) Develop a probability distribution for a random variable defined for a sample space in which **theoretical probabilities** can be calculated; find the expected value. *(CCSS Initiatives Project,* www.corestandards.org/the-standards/mathematics/hs-statistics-and-probability/)

Recall.formula.SRS_uniform.discrete $\left[p_i = P_i\left(u_i = 1 \middle| a\right) = 1/a \right]$

Recall.formula.expected_value $\left[E\left(y\right) \doteq \bar{y} = \sum_{i=1}^{n} p_i u_i \right]$

Apply.formula.sum_products $\left[\bar{y} = \sum_{i=1}^{n} p_i u_i = p_1 u_1 + p_2 u_2 + \cdots + p_n u_n \right]$

Apply.formula.simplify_distributive $\left[\sum_{i=1}^{n} p u_i = pn \middle| p = 1/a \right]$

Constraint.value.discrete_int $\left[u_i \in \left(0,1,\ldots,u^{\max}\right) \right]$

Constraint.value.discrete_int $\left[n \in \left(2,\ldots,n^{\max}\right) \right]$

Constraint.value.prob $\left[0.0 \le p \le 1.0 \right]$

A Rendering Template for Our Simple Statistics Problem

A <*sample.event*> has <*n*> <*description.sample_units*> <*description.auxiliary_info*>. <The/Each> <*description.theoretical_event_probability*>. What will be the expected <*description.value_unit(s)*> for <*description.objects_using_theoretical_prob_distrib*>?

<MCq5.distractor.1=p>
<MCq5.distractor.2=$(1/n)*a$>
<MCq5.distractor.3=$n*p=\sum_x x*p_x$>
<MCq5.distractor.4=$(1/a)\sum_x x = p\sum_x x$>
<MCq5.distractor.5=$(1/a)*p*n$>

Scoring Evaluator
u_i=CAK(*i.Selection.MCq.d*=*i.Key*,1 if *T*,0 if *F*)

Note: p=theoretical_prob_distr.constant=1/a

Approaches to Task Modeling

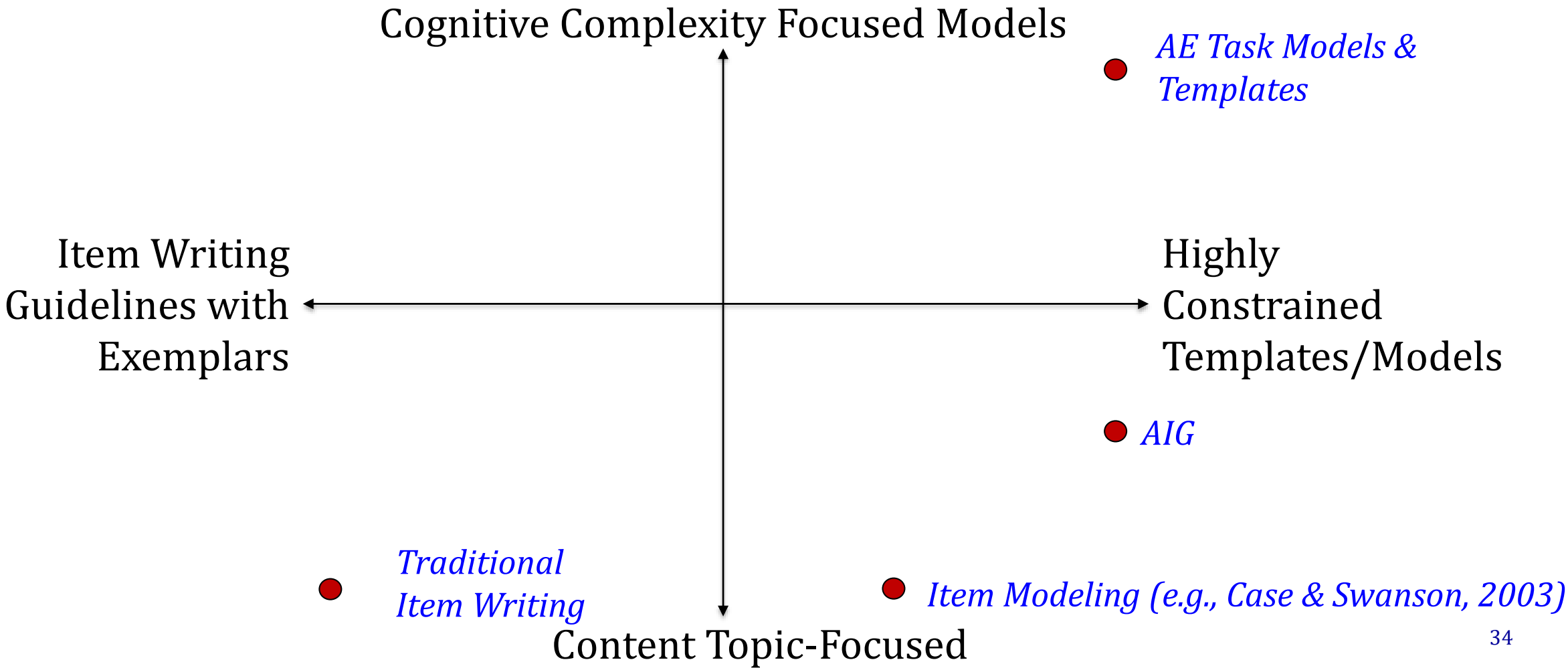
Reverse-Engineering Existing Items (Bottom-Up)

- Reverse engineering actual items to develop a TMG (propositional) or *language* to detail required skills and knowledge components
- Forward engineer templates and items from the TMG
- Iteratively refine of TMG-based families, matching empirical item difficulty ordering

Construct Mapping Approach (Top-Down)

- Develop a TMM along a trajectory
- Design cognitive task models using challenge schema where *skills* → *knowledge* | *context, tools*
- Iteratively design and validate templates and item families using a hierarchical QC approach

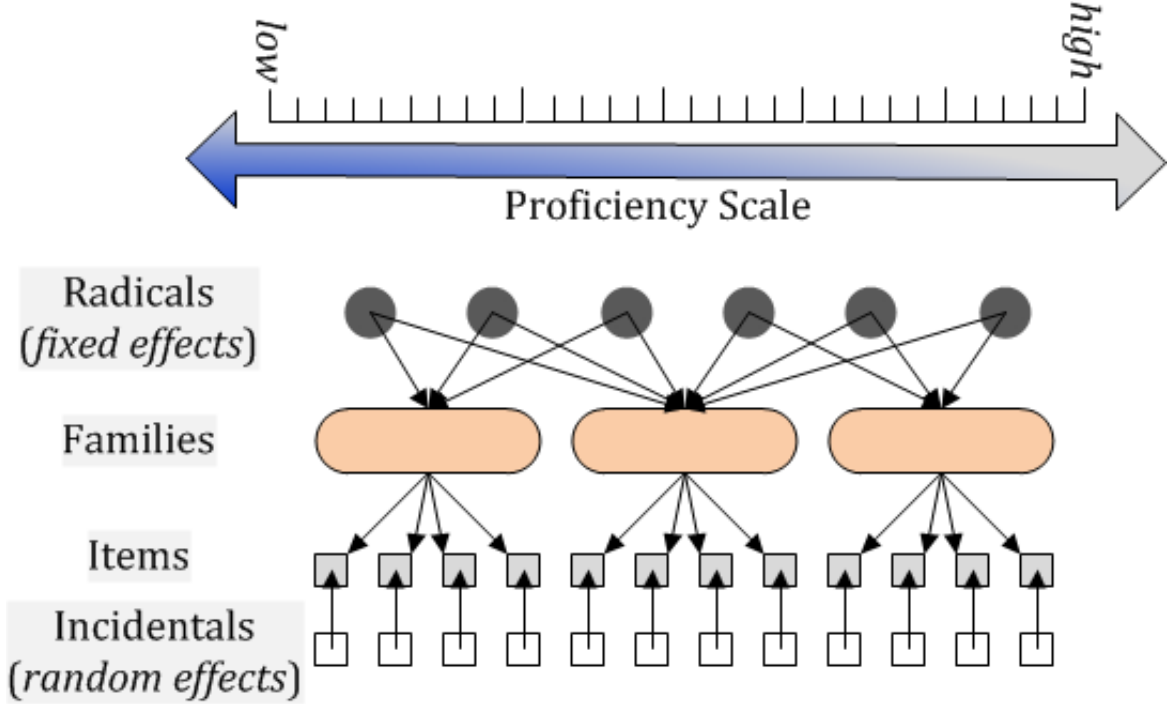
Item Models vs. Automatic Item Generation (AIG) vs. AE Task Models + Templates



Quality Control for Task Models and Templates: Items as True Item Families

AE Task Models → AE Templates → Operational Items

Measurement Opportunities



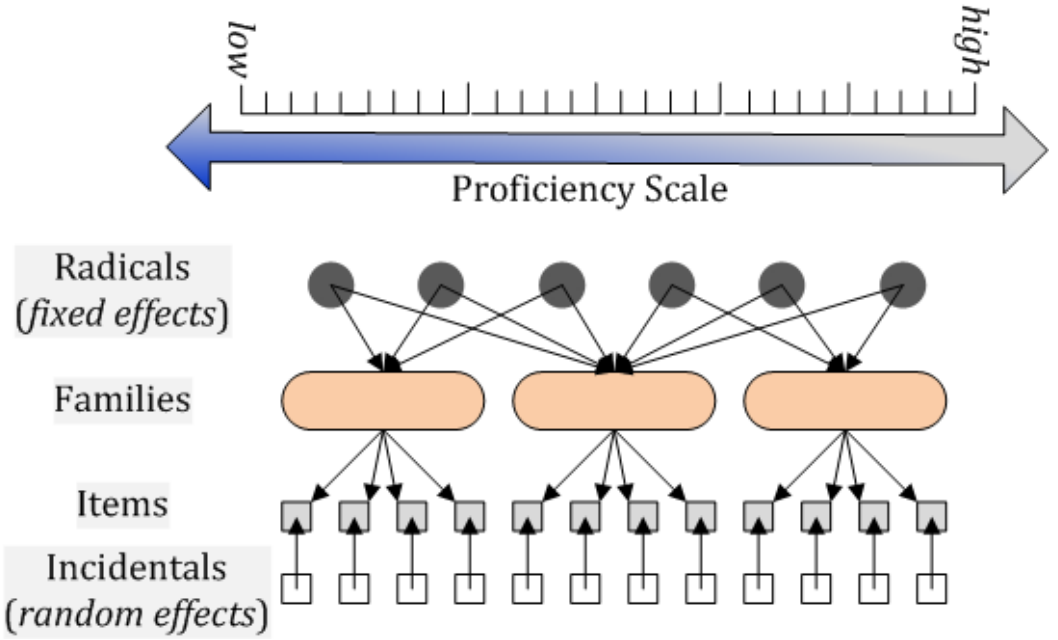
First-Level Model

$$P\left(x_{if}=1\middle|\boldsymbol{\theta};\boldsymbol{\xi}_{if}\right)=c_{if}+\left(1-c_{if}\right)\Phi\left[a_{if}\left(\theta-b_{if}\right)\right]$$

Second-Level Model

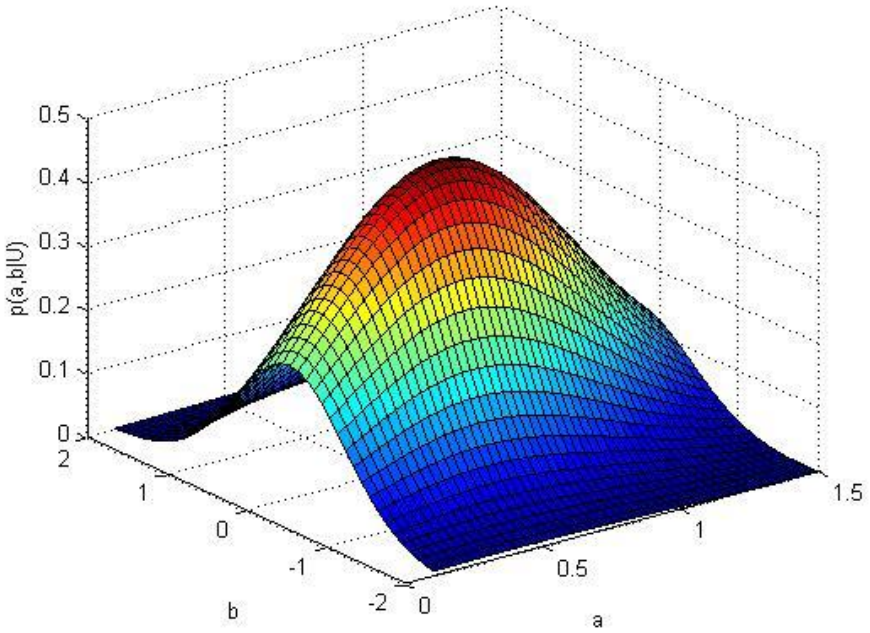
$$\boldsymbol{\xi}_{if}=MVN\left(\boldsymbol{\mu}_{f},\boldsymbol{\Sigma}_{f}\right)$$

$$\mu_{if}=\sum_{r=1}^{R}d_{fr}\beta_{r}$$

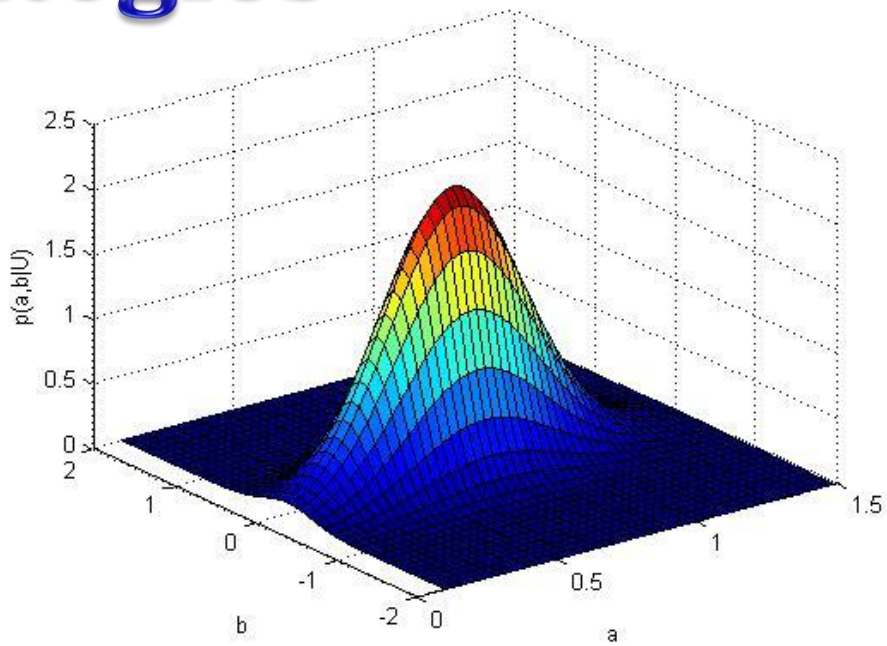


Geerlings, H., Glas, C. A. W., & van der Linden, W. J. (2011). Modeling rule-based item generation. *Psychometrika, 76*, 337-359.

QC and Variance of Item Parameter Estimates Drives Calibration Strategies

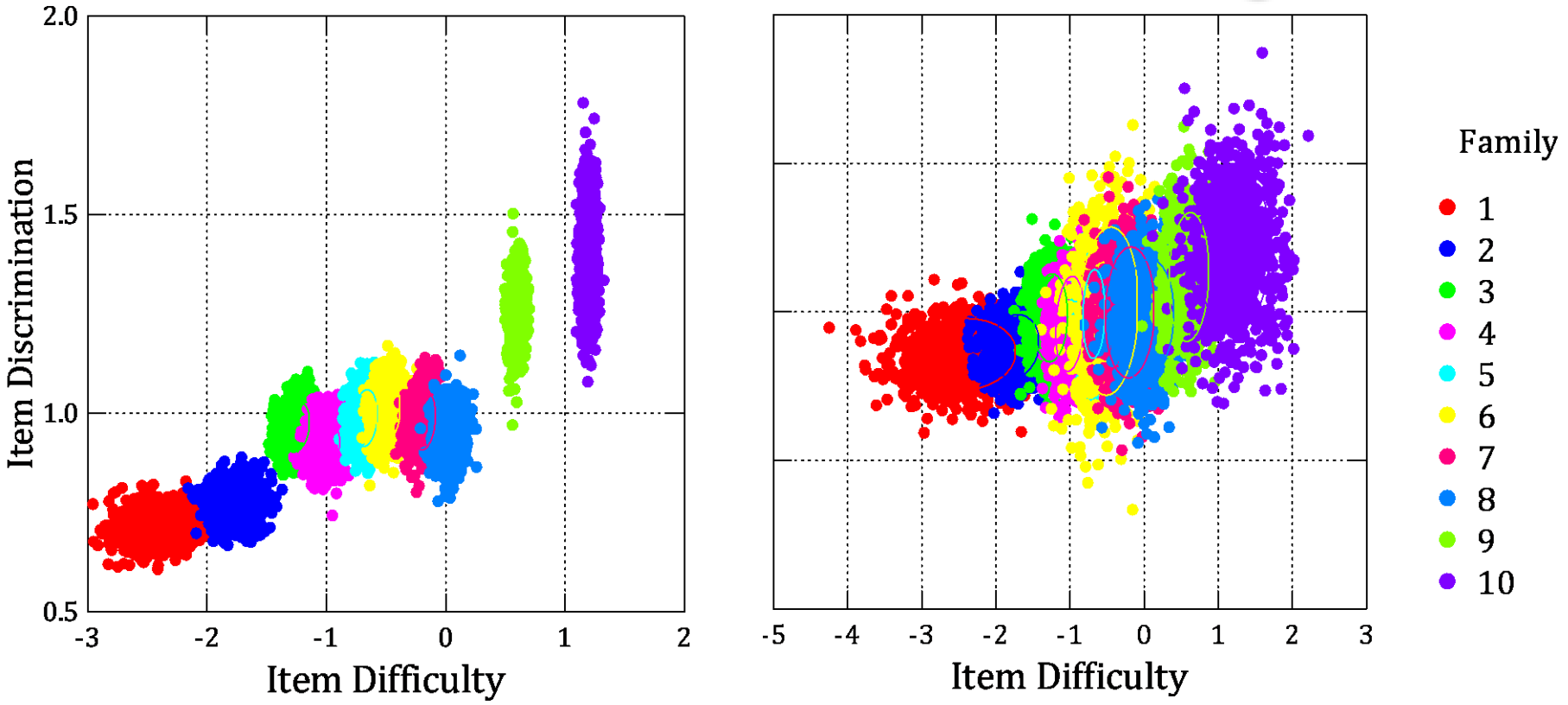


Calibrate individual items (ignore the item family)…Refine templates to reduce variation in item characteristics



Calibrate task models as families…monitor variation over time and "tweak" templates as needed

ESTIMATION and QC



QC Implications
(a) Item families are working well
(b) Calibrate TM families

QC Implications
(a) Item families not working
(b) Tighten/repair templates

39

Psychometrics becomes part of an continually active QC system aimed maintaining ROBUST SCALES using hierarchically calibrating task models or templates rather than individual items

Conclusion: Two Essential Conditions for the Success of AIG and AE

- **Substantive isomorphism** within item families
  - Cognitively exchangeable tasks in terms of required knowledge and skills
  - Exchangeable evidence to inform measurement claims
- **Statistical isomorphism** within item families
  - Sufficiently small variation of all item statistical properties within item families
  - Exchangeability of items within families for scoring purposes

Questions?

- “The world is full of magical things patiently waiting for our wits to grow sharper.”
  - Bertrand Russell

Thank you very much for your attetion!

Ric Luecht: rmluecht@gmail.com
Matt Burke: mburke@abim.org