Item Response Theory and Computerized Adaptive Testing

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Outline

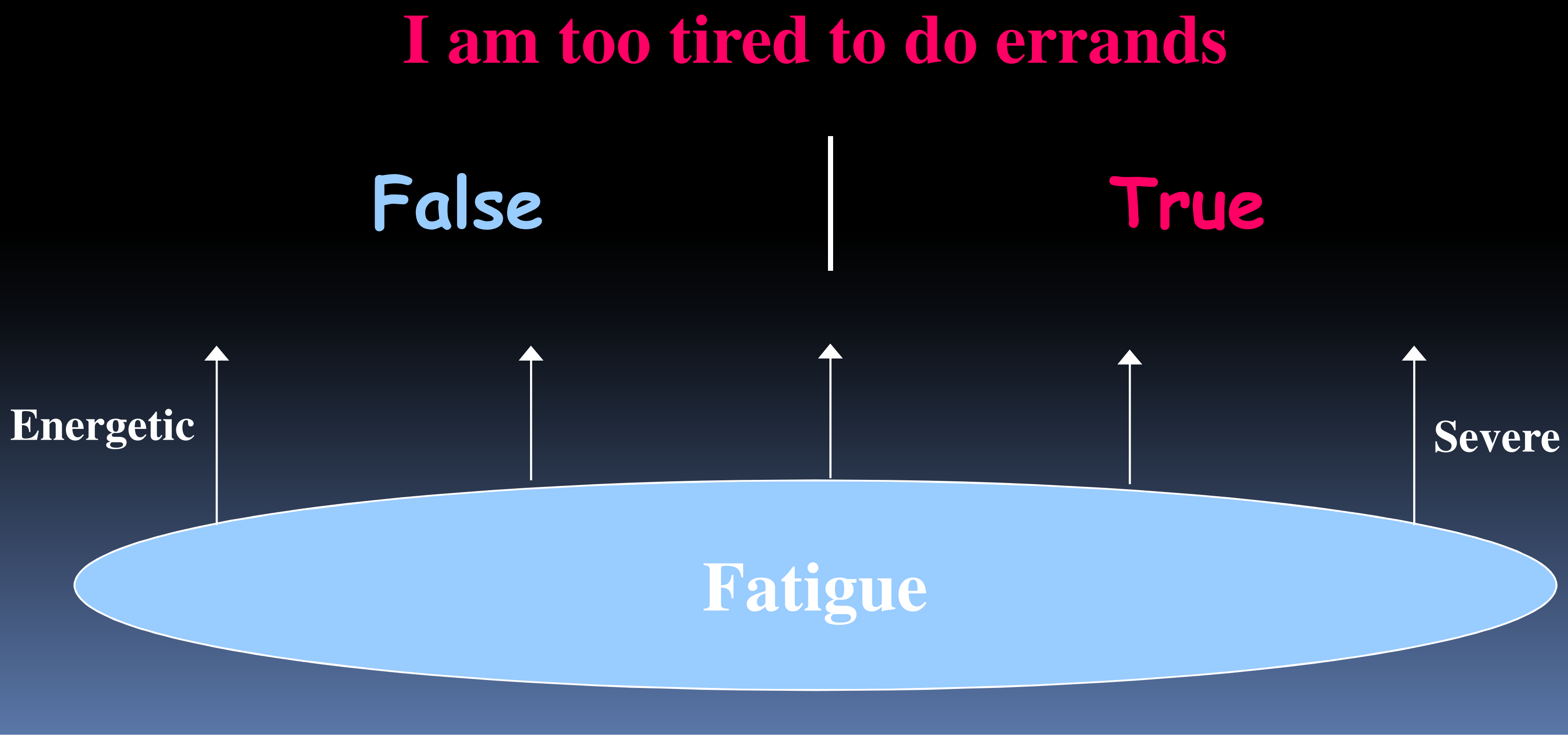
- Item Response Theory
  - versus Classical Test Theory
- Uses of IRT
  - Item Banking
  - Short Forms
  - Computerized Adaptive Tests

Requirements for Measurement

- Measurement requires the concept of an underlying trait that can be expressed in terms of more *or* less
- Test items are the operational definition of the underlying trait
- Test items
  - can be ordered from easy to hard
- Test takers
  - can be ordered from less able to more able

IRT Modeling is Latent Trait Modeling

- A latent trait is an unobservable latent dimension that is thought to give rise to a set of observed item responses.



I am too tired to do errands

False | True

Energetic

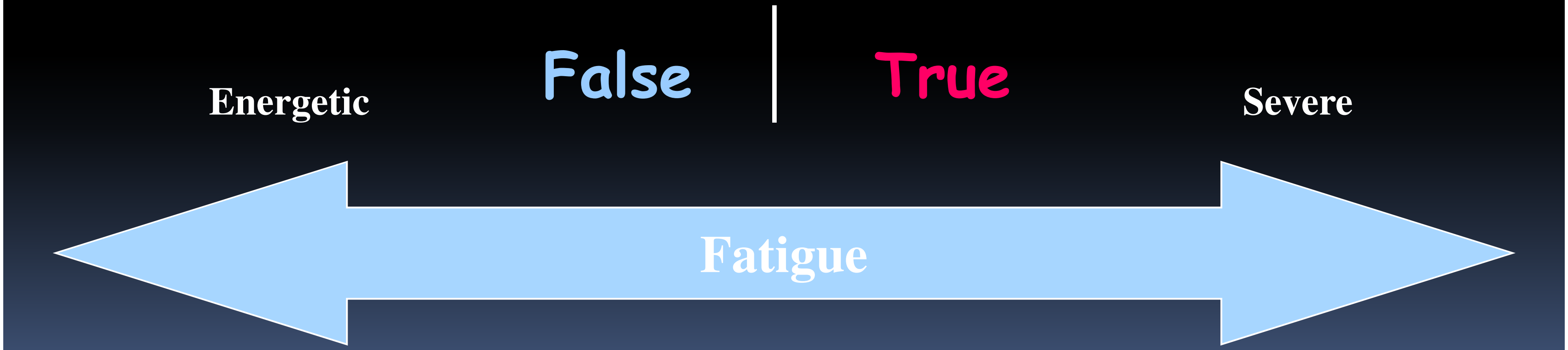
Severe

Fatigue

Latent Traits (cont.)

- These latent traits (constructs, variables, θ) are measured on a **continuum** of severity.

I am too tired to do errands?



Energetic

False

True

Severe

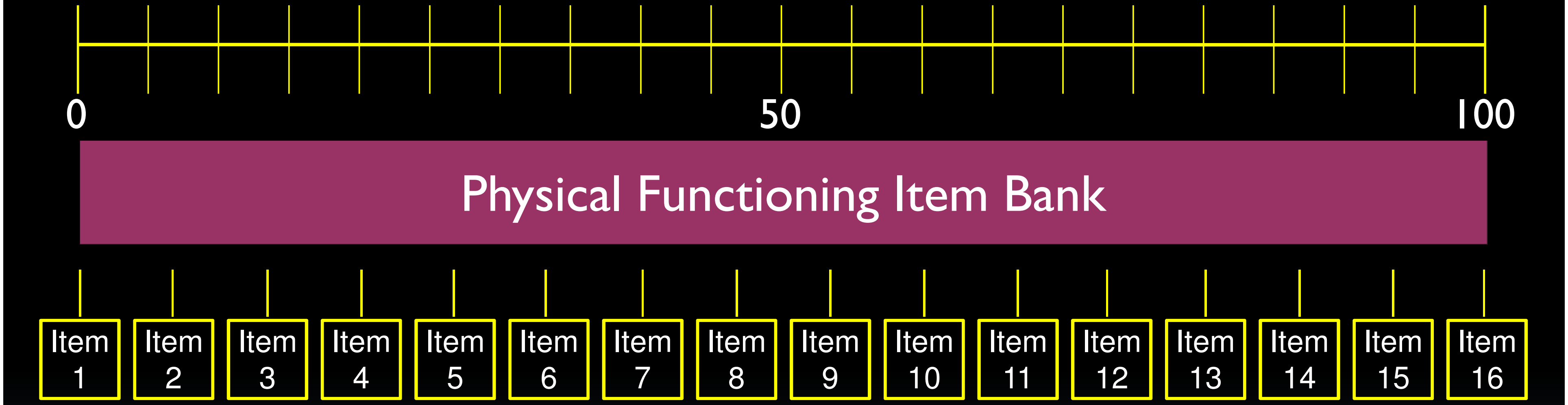
Fatigue

Advantages of Using IRT

- Equal Interval Measure
- Test-takers and items are represented on the same scale
- Item calibrations are independent of the test-takers used for calibration
- Candidate ability estimates are independent of the particular set of items used for estimation
- Measurement precision is estimated for each person and each item

Test-takers and Items are Represented on the Same Scale

- Item Difficulty = Severity = Measure = Theta = Item Calibration = Location
- Person Ability = Measure = Theta = Person Calibration = Location



0

50

100

Physical Functioning Item Bank

Item 1 | Item 2 | Item 3 | Item 4 | Item 5 | Item 6 | Item 7 | Item 8 | Item 9 | Item 10 | Item 11 | Item 12 | Item 13 | Item 14 | Item 15 | Item 16

Are you able to get in and out of bed?
Are you able to walk a block on flat ground?
Are you able to run five miles?

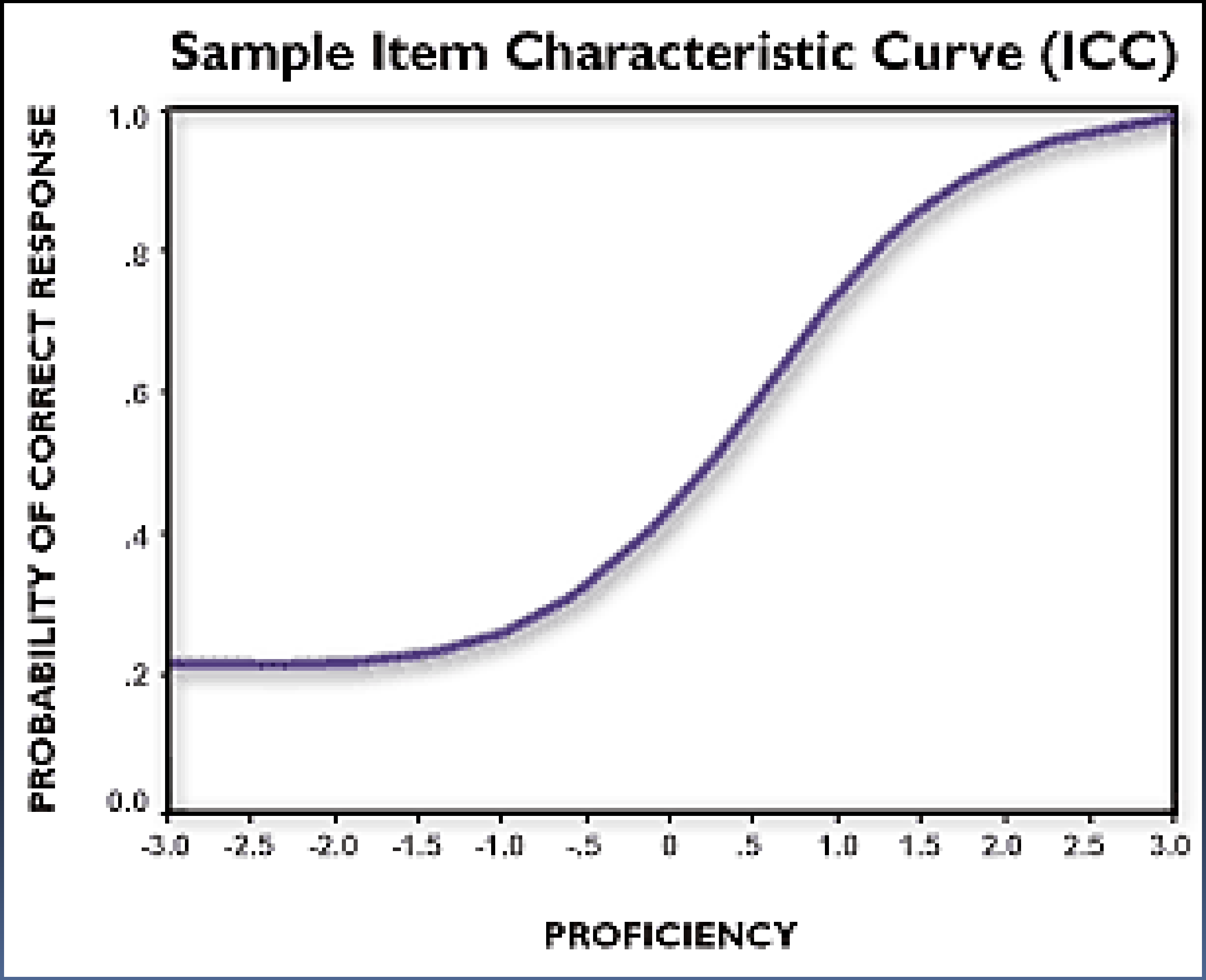
More Basic Terms

- Discrimination = the degree to which an item discriminates person ability
- Item Information = the area where an item discriminates
- Test Information = the area where the test discriminates

Item “Parameters”

- IRT statistics about an item
- Primary: Item Difficulty
- Often: Item Discrimination
- Sometimes: Guessing
- Lots of other “ugly looking numbers”

The Item Characteristic Curve



Differential Item Functioning (DIF)

- Does an item have different item parameters for different subgroups?
- Gender
- Race
- Age
- Disease

The Three Main IRT Models

- Rasch model one parameter logistic model (1PL)
- Two parameter logistic model (2PL)
- Three parameter logistic model (3PL)

How to choose an appropriate IRT Model

OR

My religion is better than your religion!

WARNING!

You are about to see mathematical formulas!

One Parameter Logistic Model

$$P_{1,0} = \frac{e^{(ability\ -\ difficulty)}}{1 + e^{(ability\ -\ difficulty)}}$$

When the difficulty of a given item exactly matches the Examinee's ability level, then the person has 50% chance of answering that item correctly:

$$P_{1,0} = \frac{e^{(0)}}{1 + e^{(0)}} = \frac{1}{2} = .50$$

One Parameter Logistic Model

- Only option for small sample sizes
- Often the real model underlying a test labeled as three parameter
- Less costly
- “The simple solution is always the best”

Two Parameter Logistic Model

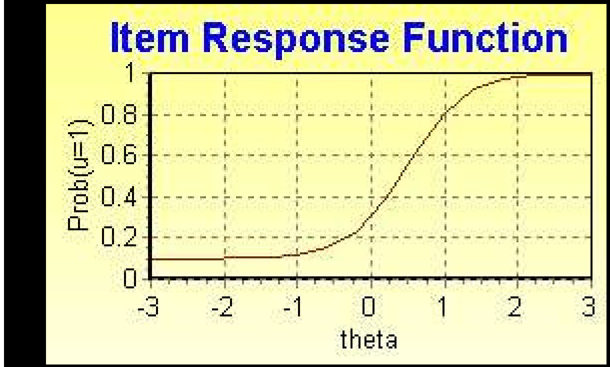
$$P_{1,0} = \frac{e^{a\,(ability\,-\,b)}}{1 + e^{a\,(ability\,-\,b)}}$$

Two parameters

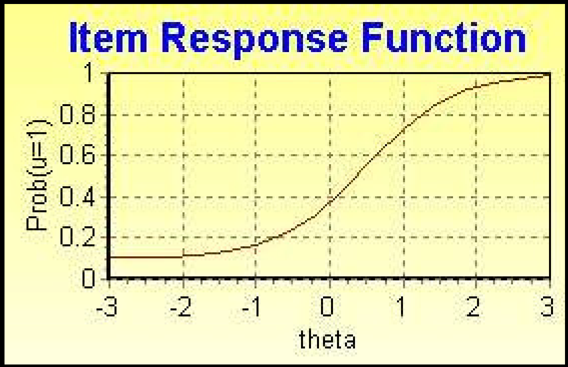
a=Discrimination

b=Item Difficulty

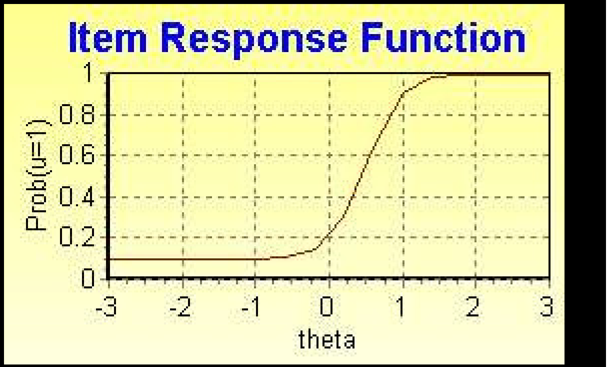
Two Parameter Examples



a=.5,b=.5



a=1.5,b=.5



a=2.5,b=.5

Three Parameter Logistic Model

$$P_{1,0} = c + (1\text{-}c)\,\frac{e^{a\,(ability\,-\,b)}}{1 + e^{a\,(ability\,-\,b)}}$$

Three parameters

a= Discrimination

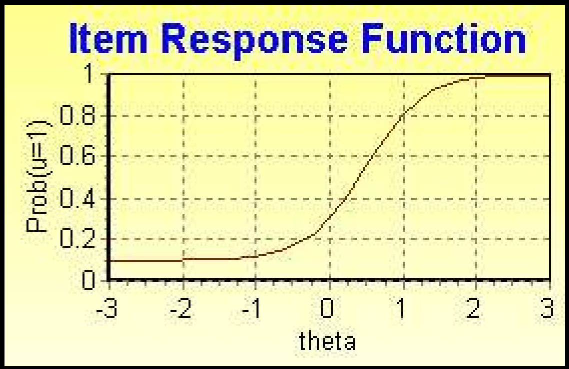
b= Item Difficulty

c= Guessing

Three Parameter Logistic Model (3PL)

- Requires a large sample size
- Significant research demonstrating that theoretically 3PL is better, but practically has little advantage over 1PL
- "Most accepted theoretical model"

Three Parameter Examples



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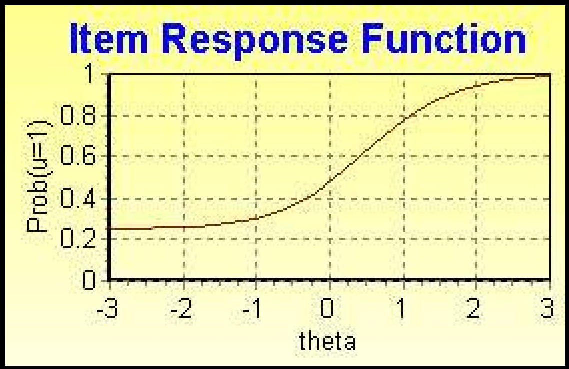


a=2.5,b=.5,c=.25

Polytomous Models

One Parameter

- Rating Scale Model
- Partial Credit Model

Two Parameter

- Graded Response Model
- Generalized Partial Credit Model

Multi-dimensional Models

There are also IRT models which consider more than one unidimensional trait at a time

How does IRT differ from conventional test theory?

Classical Test Theory

- An individual takes an assessment
- Their total score on that assessment is used for comparison purposes
- High Score – The person is higher on the trait
- Low Score-The person is lower on the trait

Item Response Theory

- Each individual item can be used for comparison purposes
- Person endorses better rating on “hard items”- The person is higher on the trait
- Person endorses worse rating on “easy items” - The person is lower on the trait
- Items that measure the same construct can be aggregated into longer assessments

Reliability

CTT

- Reliability is based upon the total test.
- Regardless of patient "ability", reliability is the same.

IRT

- Reliability is calculated for each patient "ability" and varies across the continuum.
- Typically, there is better reliability in the middle of the distribution.

Validity

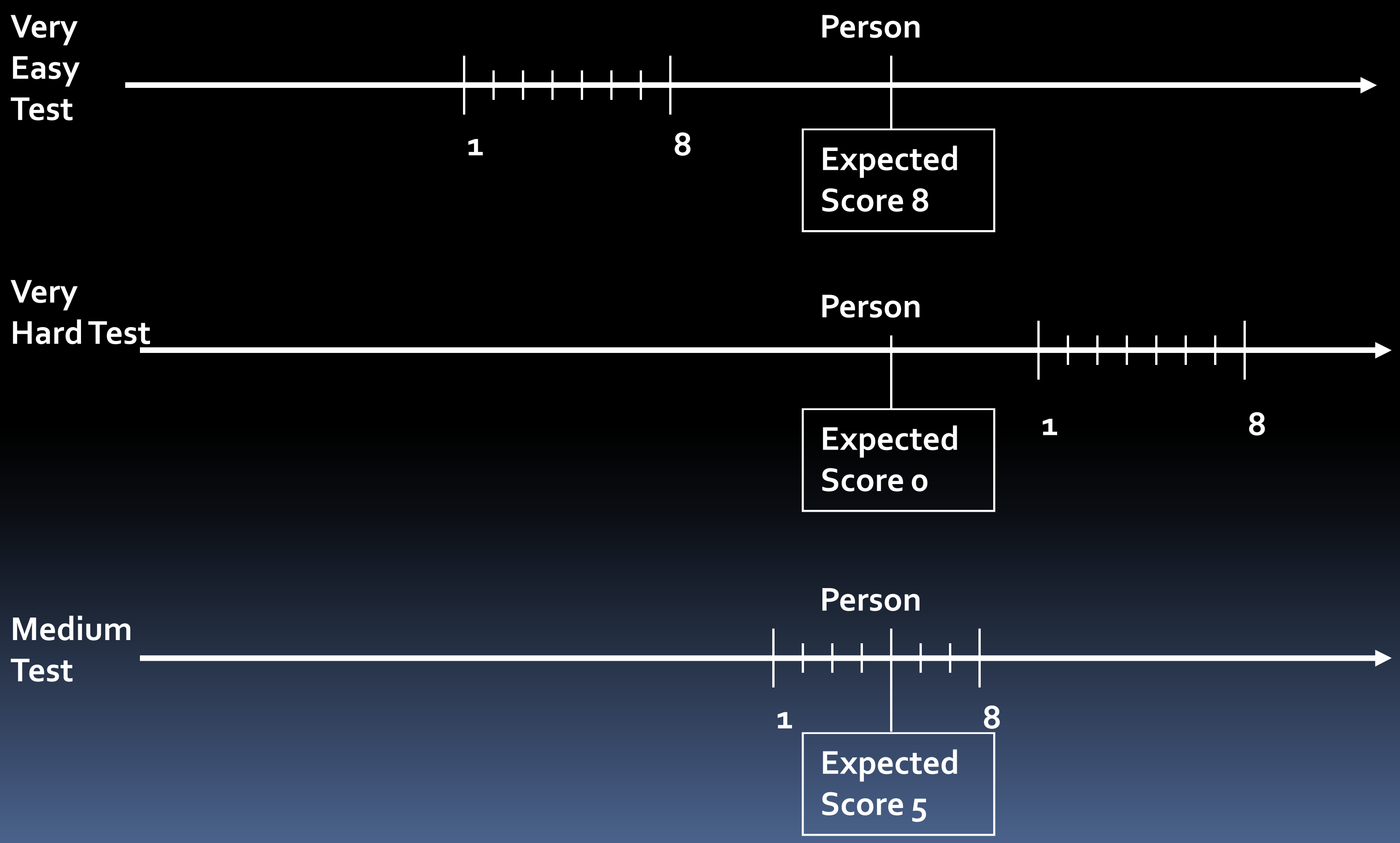
CTT

- Validity is based upon the total test.
- Typically, validity would need to be re-assessed if the instrument is modified in any way.

IRT

- Validity is assessed for the entire item bank.
- Subsets of items (full length tests, short forms and CAT) all inherit the validity assessed for the original item bank.

How Scores Depend on the Difficulty of Test Items

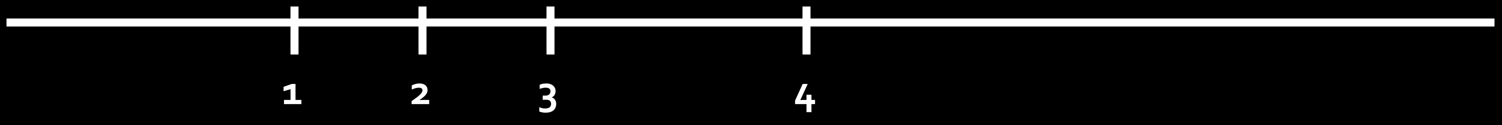


Reprinted with permission from: Wright, B.D. & Stone, M. (1979) *Best test design*, Chicago: MESA Press, p. 5.

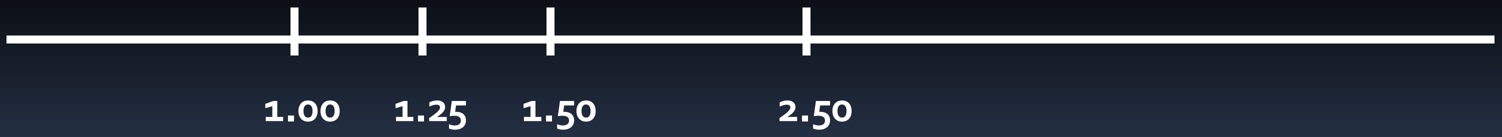
Raw Scores vs. IRT Measures
IRT has Equal Interval Measurement

4 Item Test

Raw:



Logit Measures:



I Have a Lack of Energy

Traditional Test Theory

4 = Not at All 3 = A Little Bit 2 = Somewhat 1 = Quite a Bit 0 = Very Much

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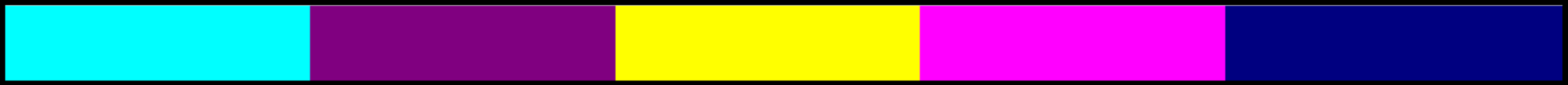

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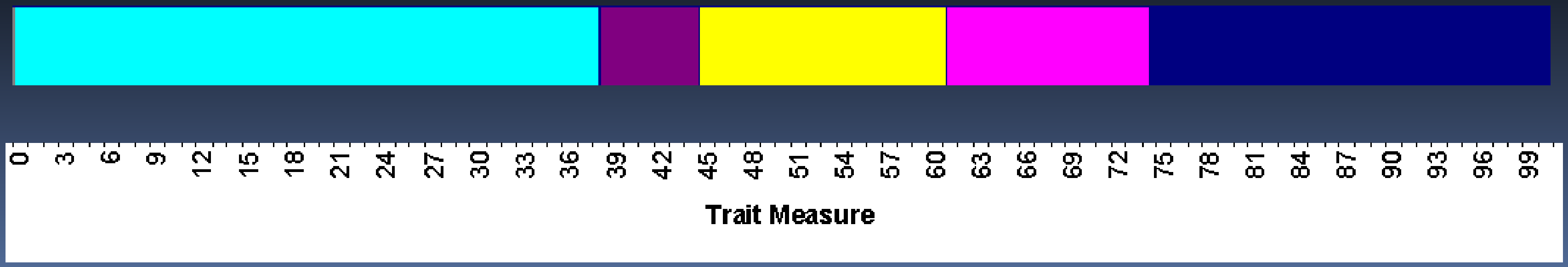
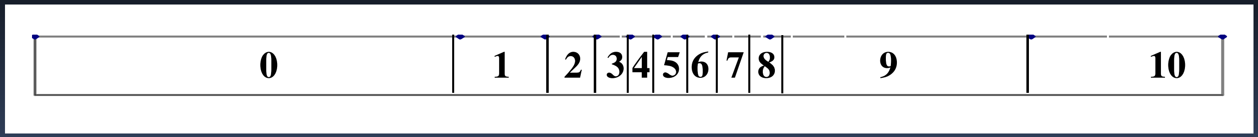
Item Response Theory



The IRT “Reality” of a 10 Point Rating-Scale Item

0	1	2	3	4	5	6	7	8	9	10

No Pain Worst Pain



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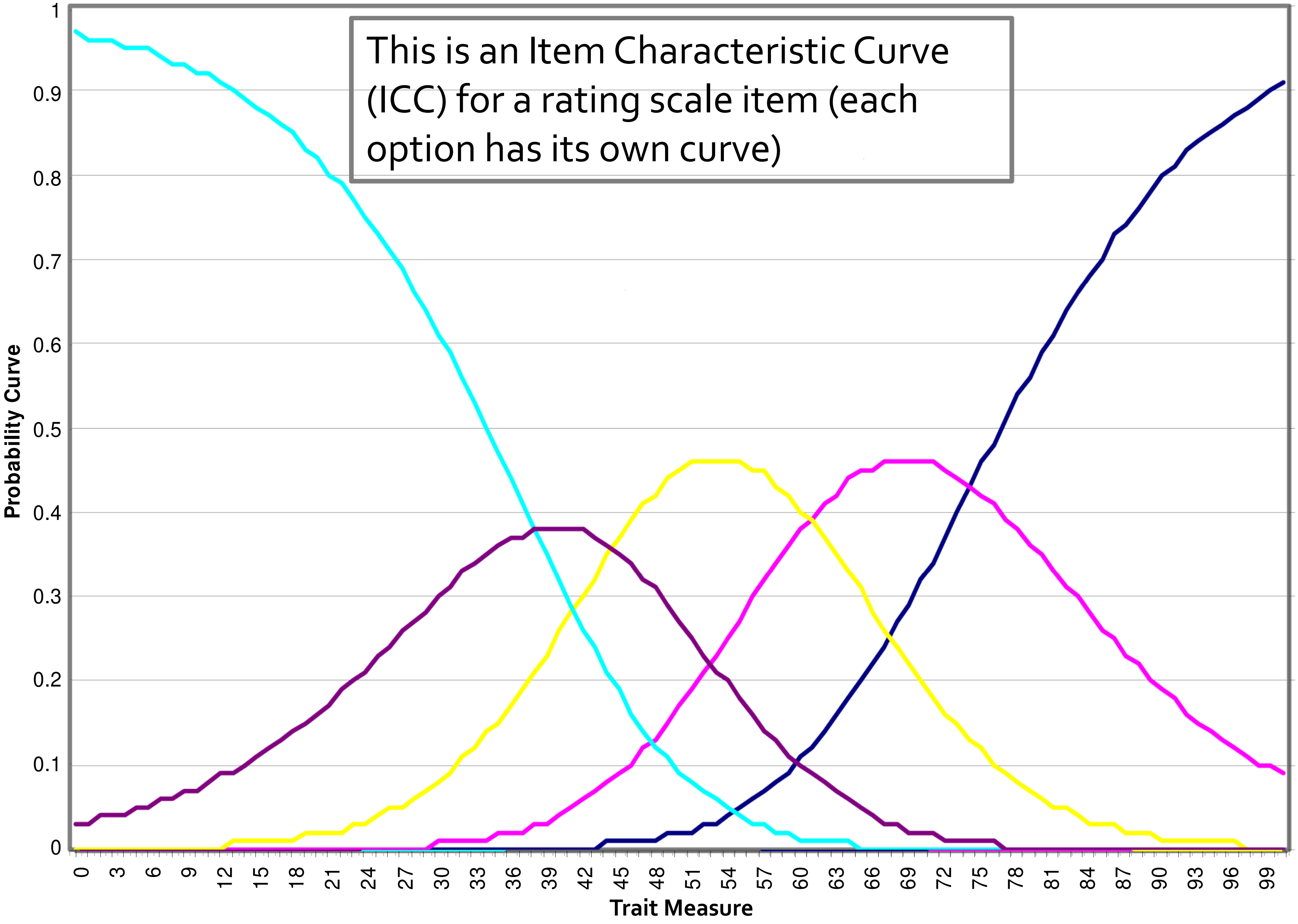

This is an Item Characteristic Curve (ICC) for a rating scale item (each option has its own curve)

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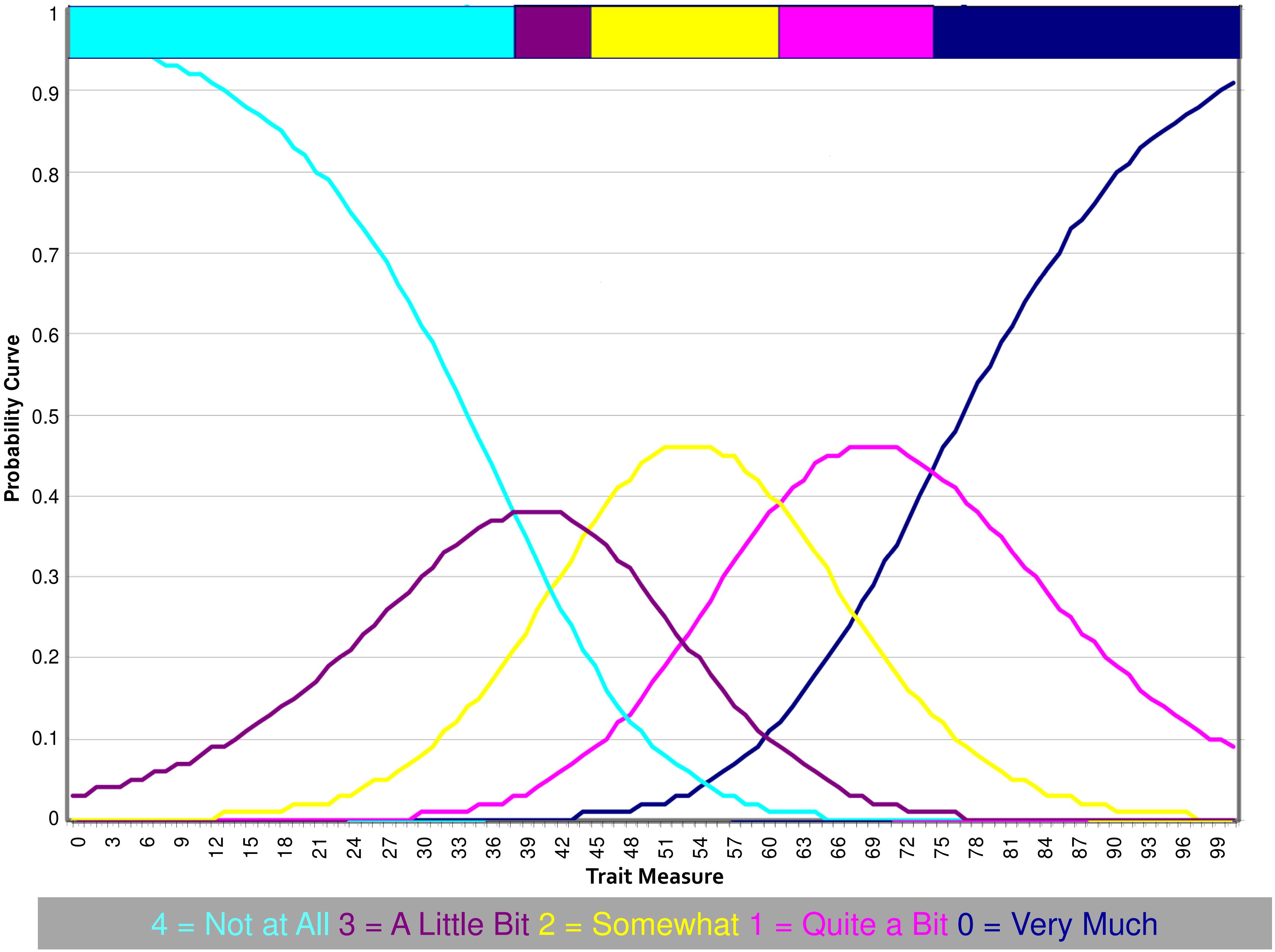

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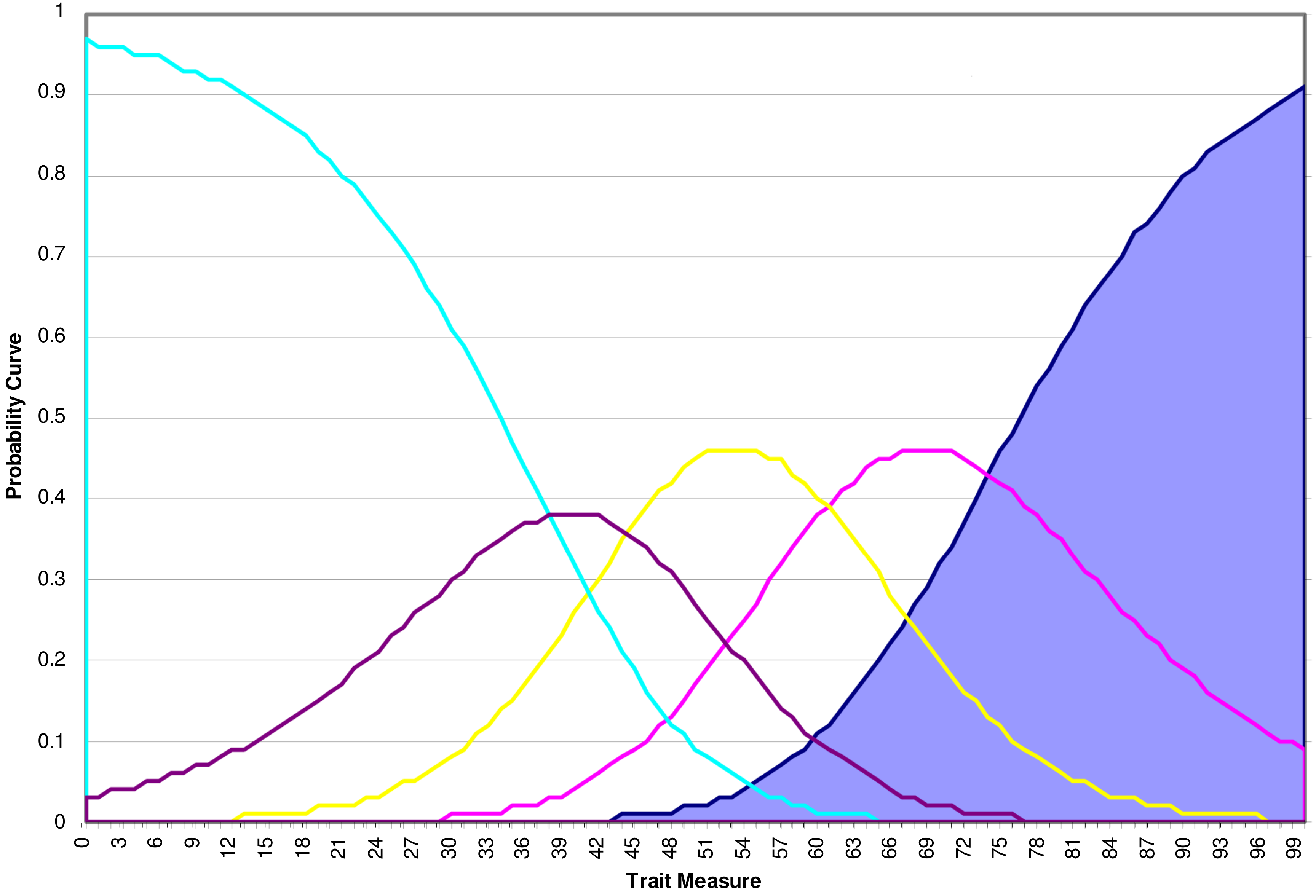

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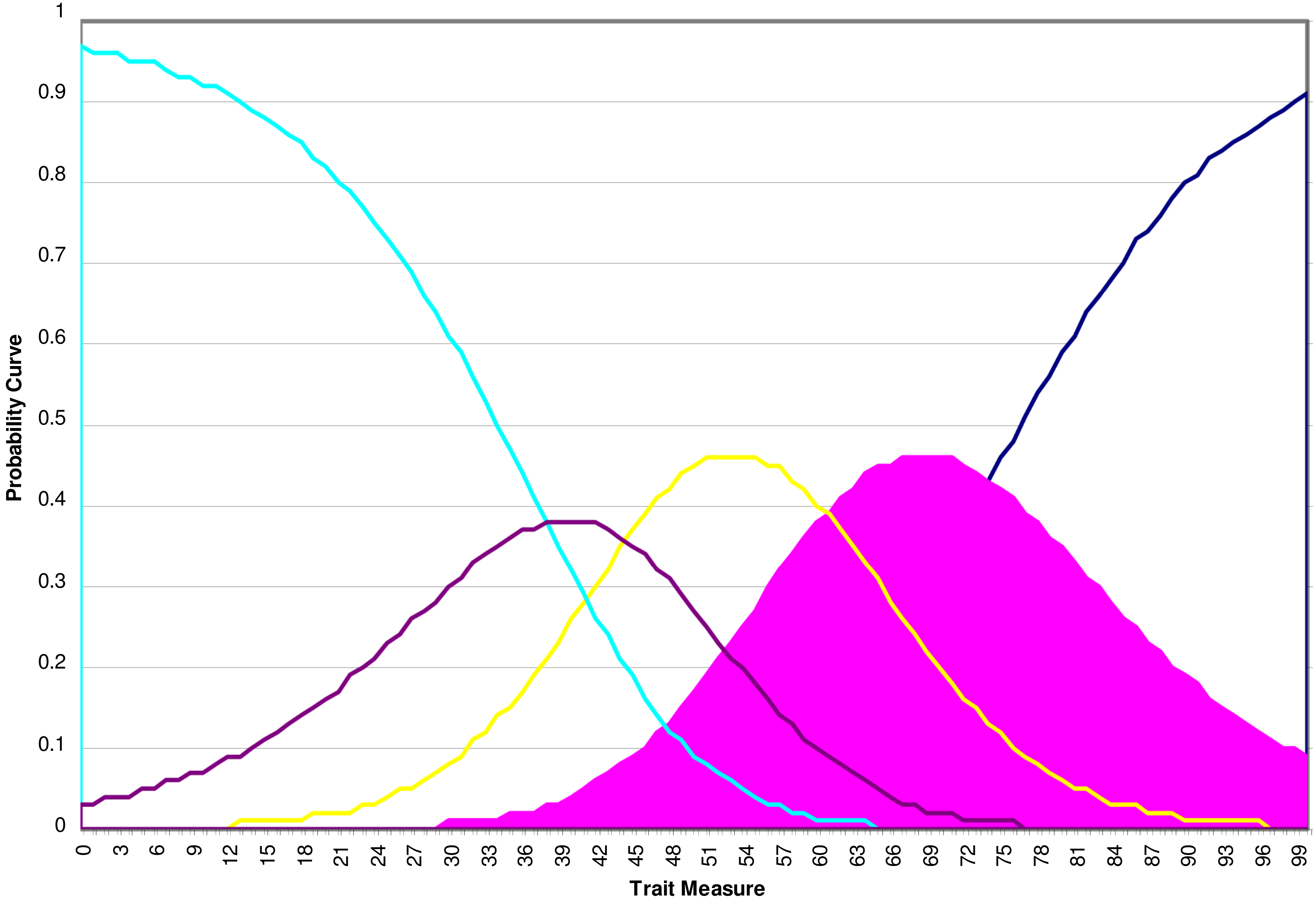

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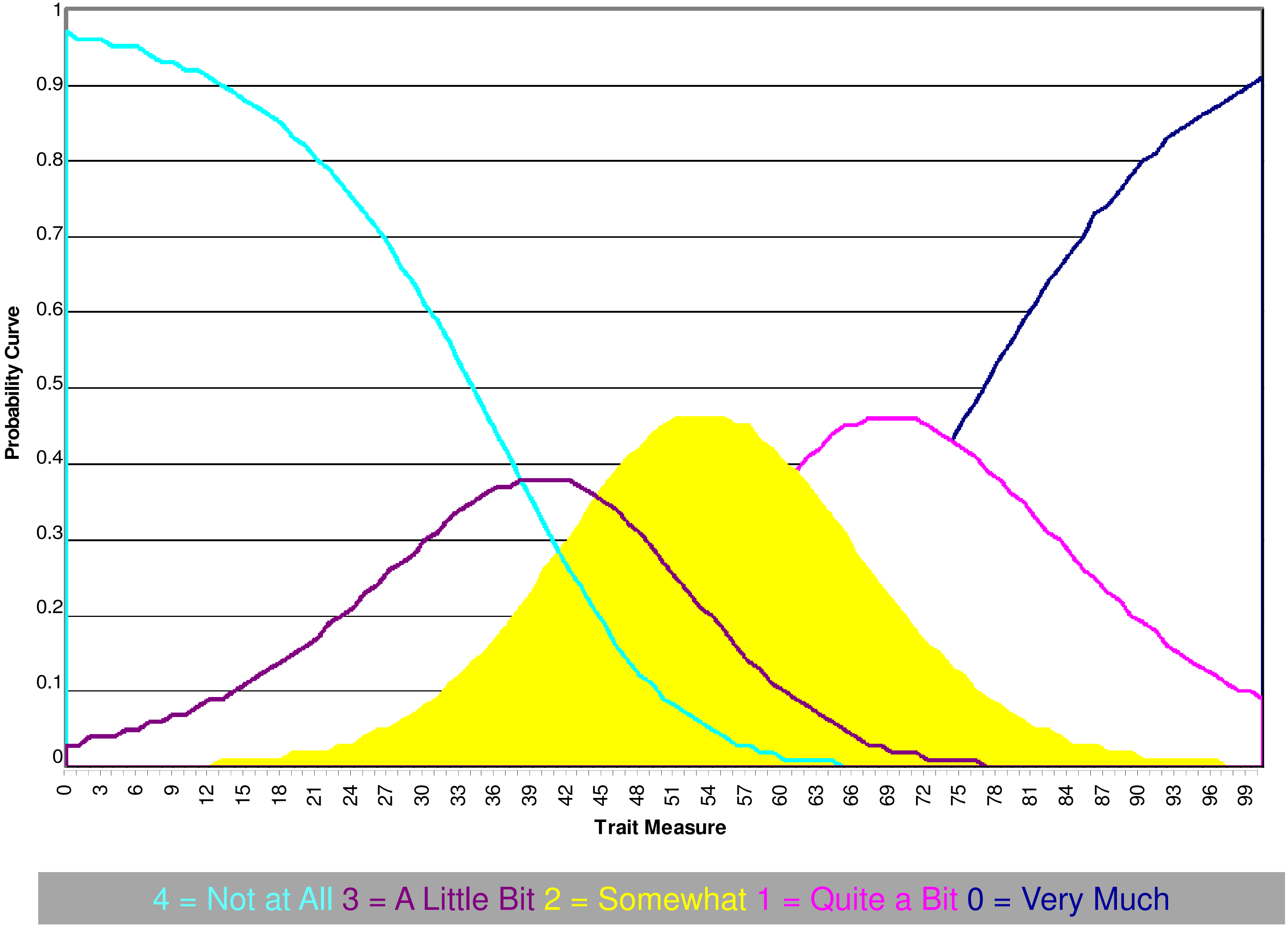

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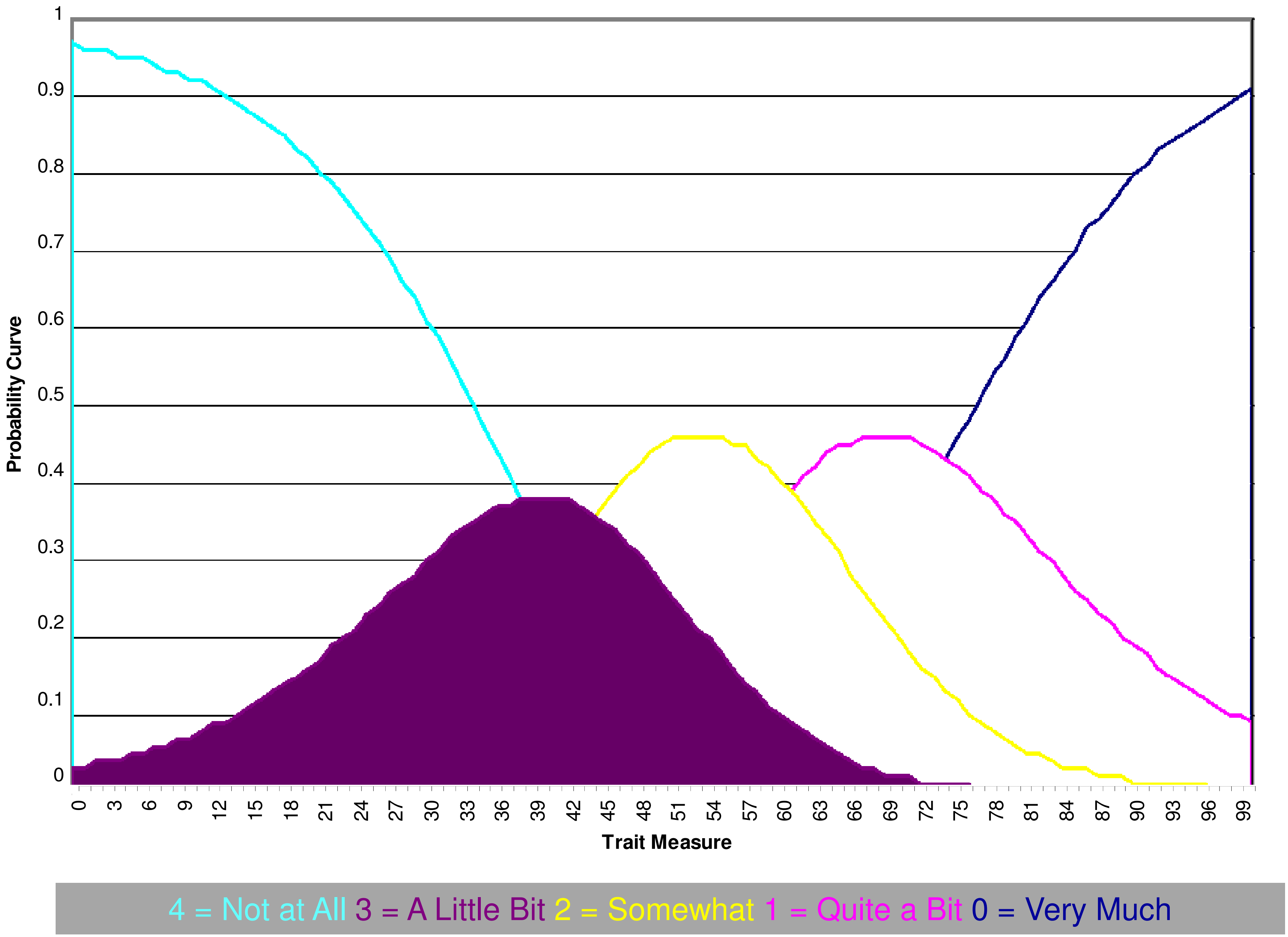

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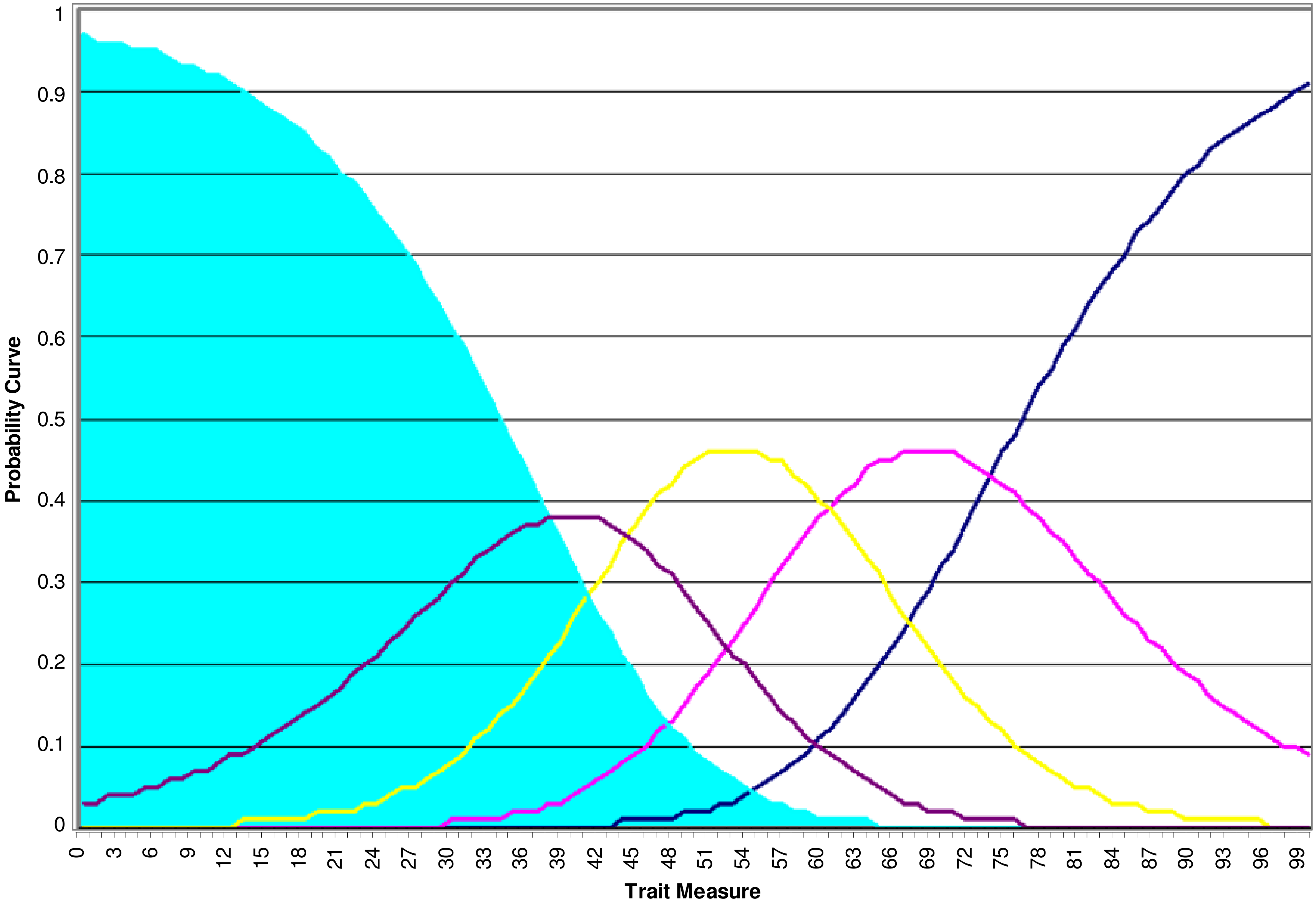

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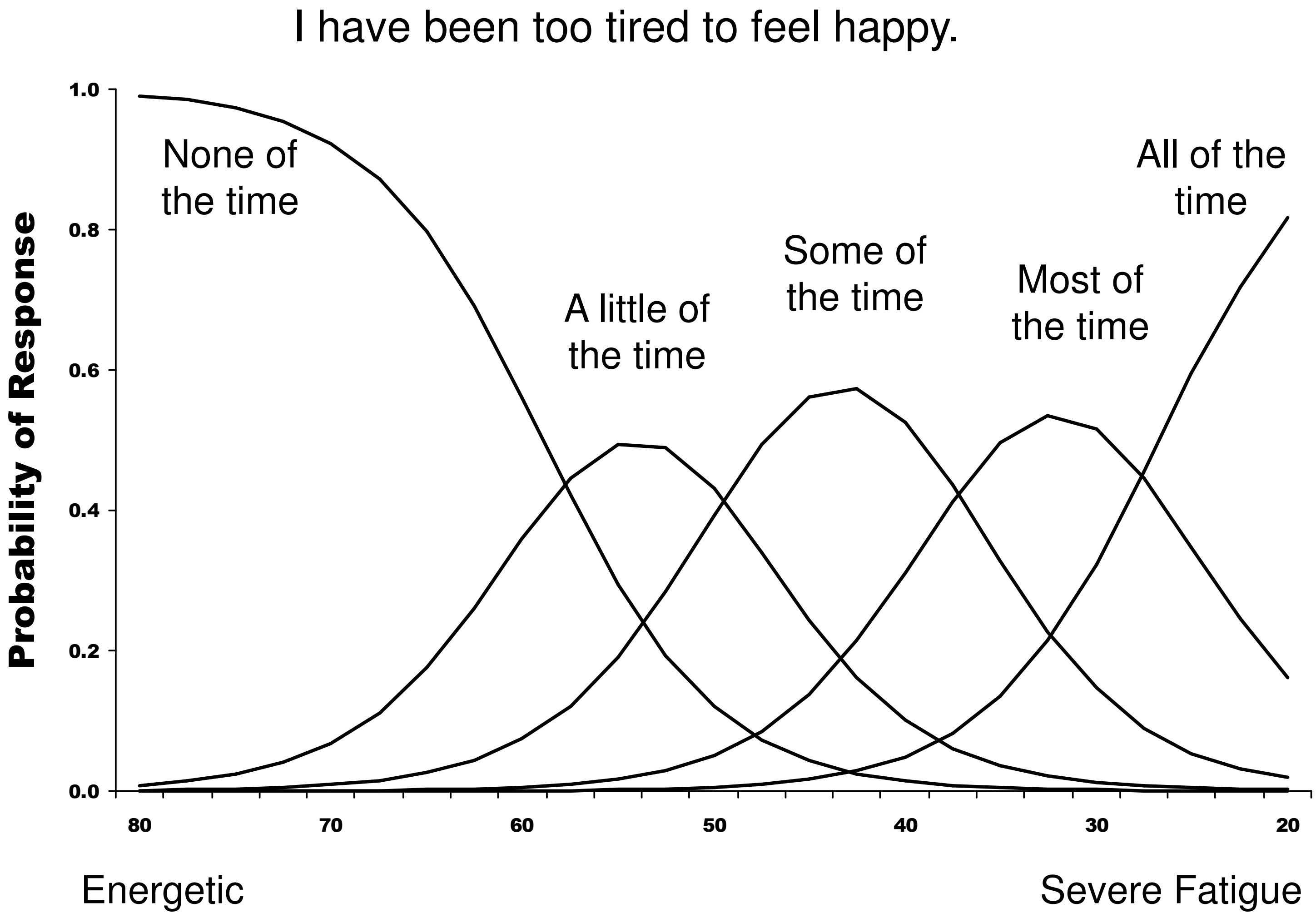
IRT Polytomous Responses



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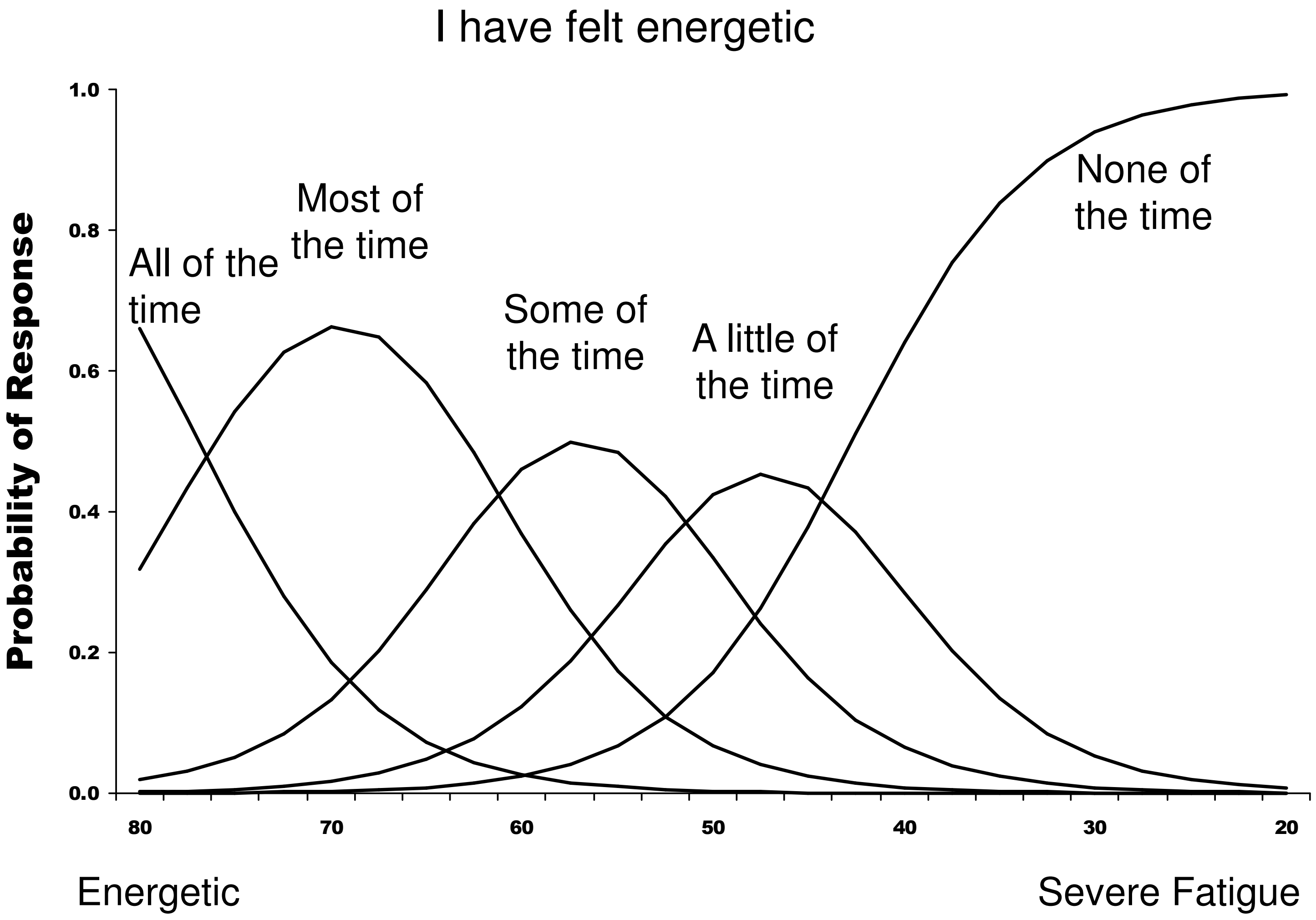

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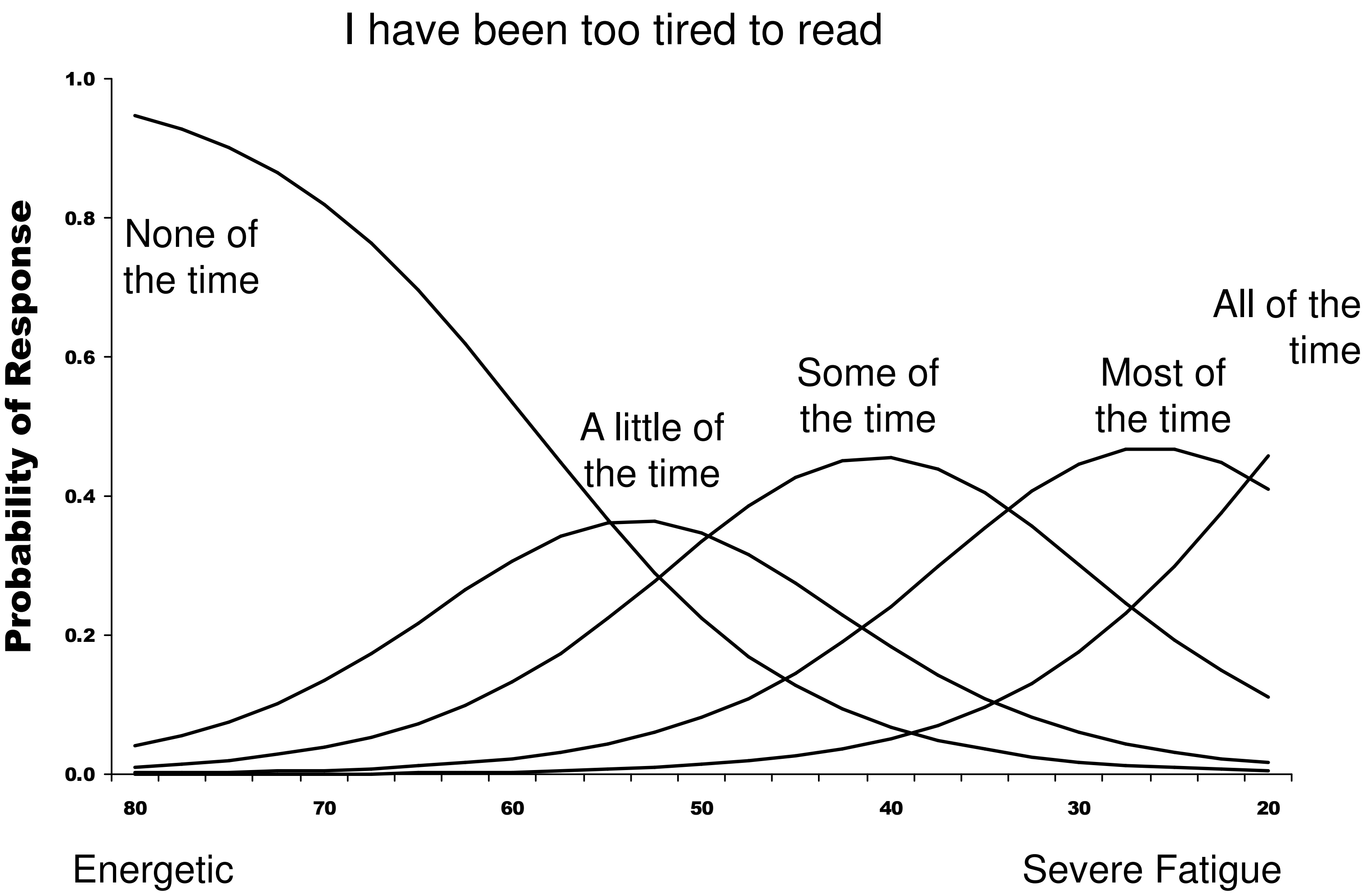
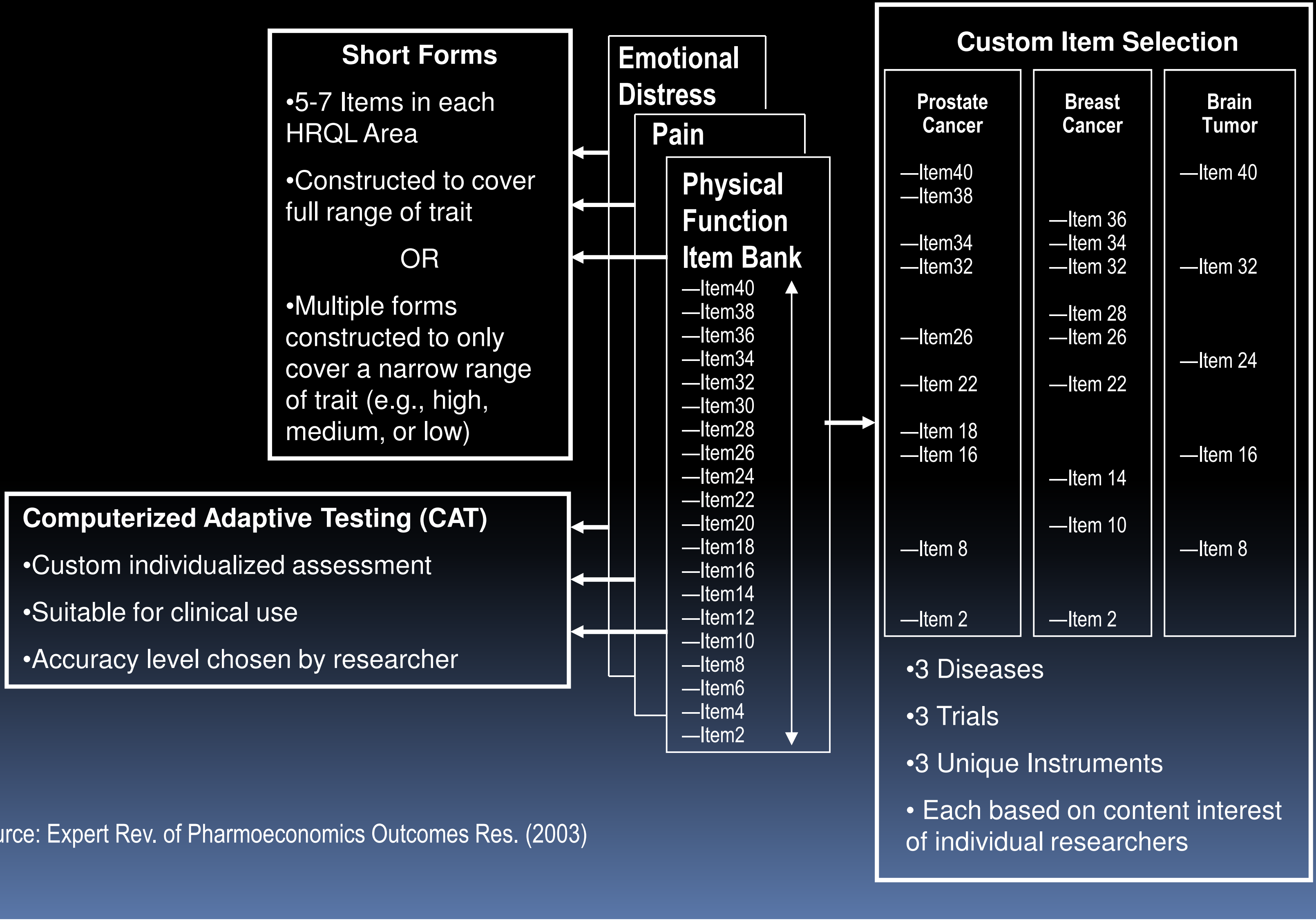


Item Banking

Calibrated Item Banks can be used to Create Numerous Instrument Types



Short Forms

- •5-7 Items in each HRQL Area
- •Constructed to cover full range of trait

OR

- •Multiple forms constructed to only cover a narrow range of trait (e.g., high, medium, or low)

Computerized Adaptive Testing (CAT)

- •Custom individualized assessment
- •Suitable for clinical use
- •Accuracy level chosen by researcher

Emotional Distress

Pain

Physical Function Item Bank

—Item40
—Item38
—Item36
—Item34
—Item32
—Item30
—Item28
—Item26
—Item24
—Item22
—Item20
—Item18
—Item16
—Item14
—Item12
—Item10
—Item8
—Item6
—Item4
—Item2

Custom Item Selection

Prostate Cancer

—Item40
—Item38
—Item34
—Item32
—Item26
—Item 22
—Item 18
—Item 16
—Item 8
—Item 2

Breast Cancer

—Item 36
—Item 34
—Item 32
—Item 28
—Item 26
—Item 22
—Item 14
—Item 10
—Item 2

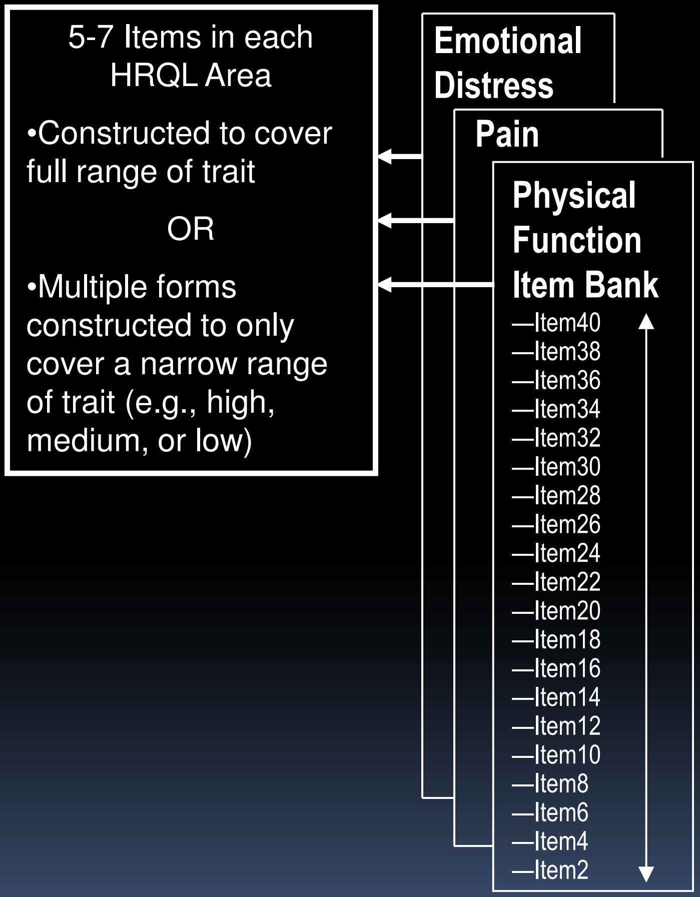
Brain Tumor

—Item 40
—Item 32
—Item 24
—Item 16
—Item 8

- •3 Diseases
- •3 Trials
- •3 Unique Instruments
- • Each based on content interest of individual researchers

Source: Expert Rev. of Pharmoeconomics Outcomes Res. (2003)

Short Forms



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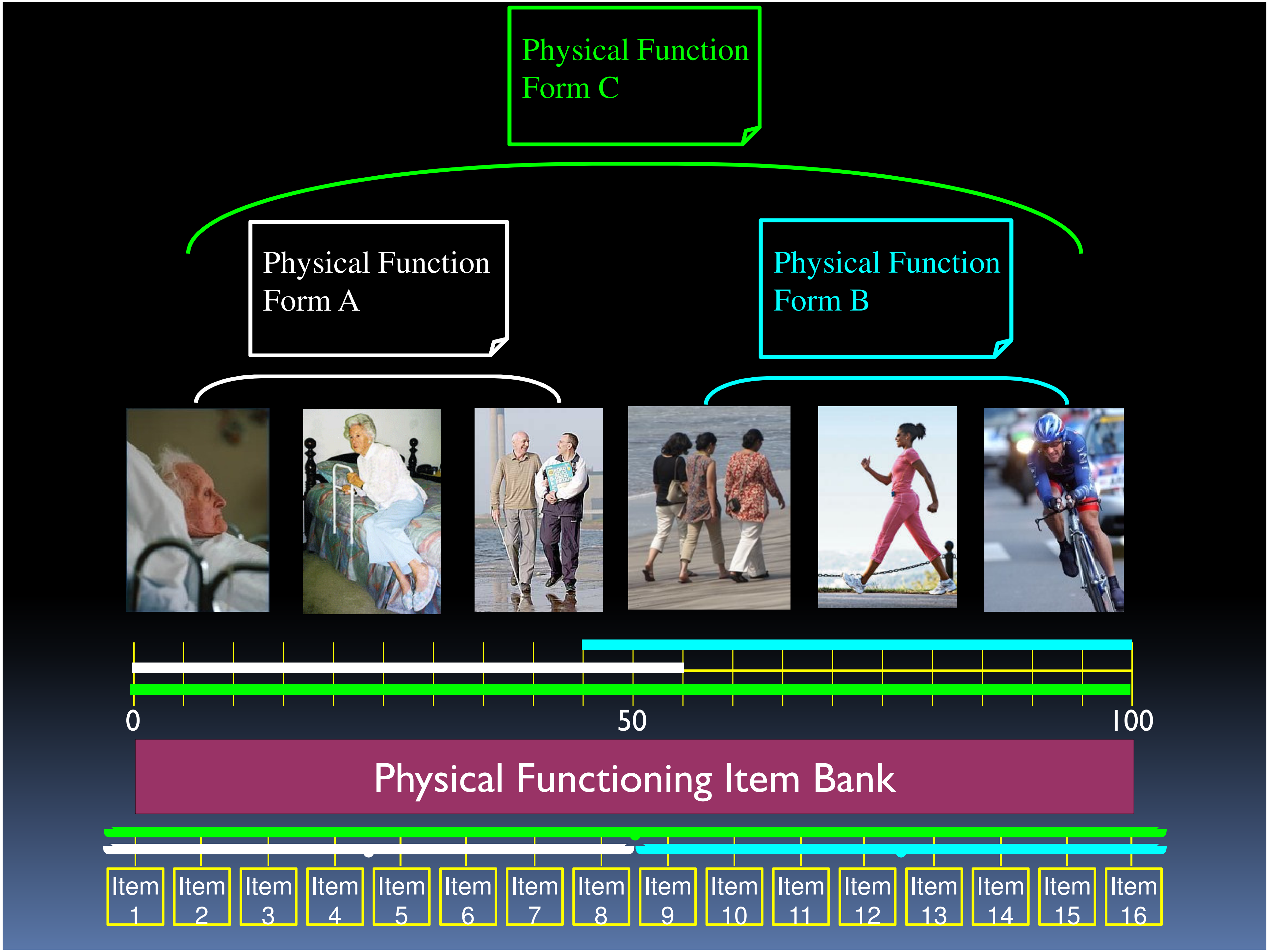


Physical Function
Form C

Physical Function
Form A

Physical Function
Form B

0

50

100

Physical Functioning Item Bank

Item 1

Item 2

Item 3

Item 4

Item 5

Item 6

Item 7

Item 8

Item 9

Item 10

Item 11

Item 12

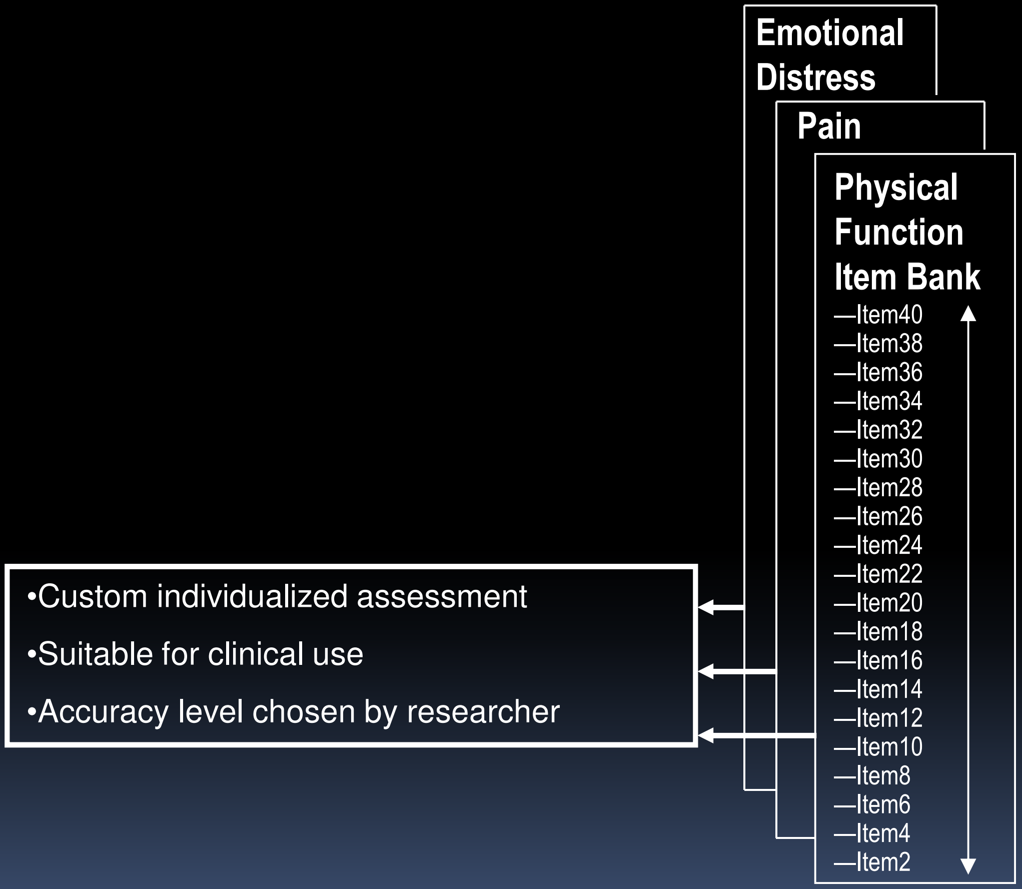
Item 13

Item 14

Item 15

Item 16

Computerized Adaptive Testing (CAT)



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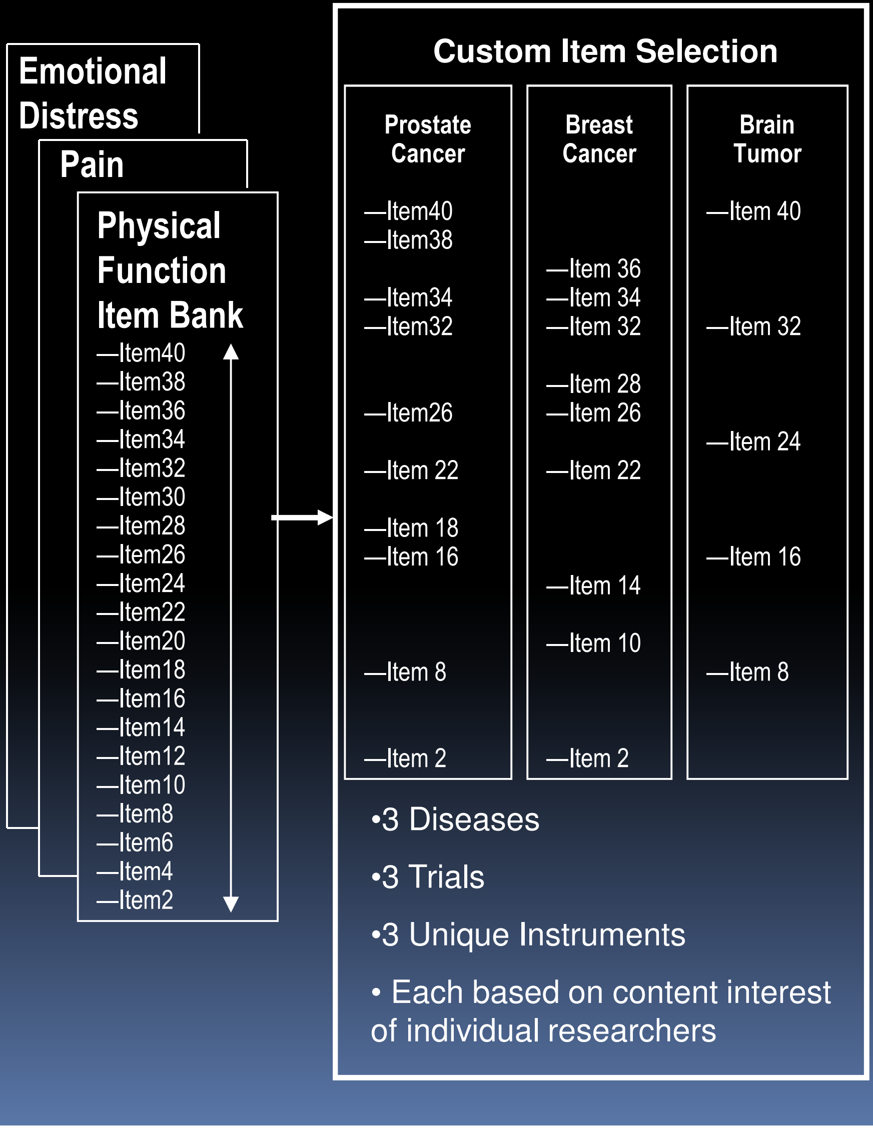
Custom Item Selection



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Custom Item Selection

Prostate Cancer	Breast Cancer	Brain Tumor
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	—Item 36	
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—Item32	—Item 32	—Item 32
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—Item26	—Item 26	
		—Item 24
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—Item 18		
—Item 16		—Item 16
	—Item 14	
	—Item 10	
—Item 8		—Item 8
—Item 2	—Item 2	

•3 Diseases

•3 Trials

•3 Unique Instruments

• Each based on content interest of individual researchers

Source: Expert Rev. of Pharmoeconomics Outcomes Res. (2003)

In Summary,
Calibrated Item Banks can be used to:

- Create a standard static instrument
- Construct short forms
- Enable CAT
- Select items based on unique content interests and formulate custom short-form or full-length instruments

In every case, using a validated,
pre-calibrated item bank allows any of these instruments to be pre-validated and produce standardized scores on the same scale

Computerized

Adaptive

Testing

What is Computerized Adaptive Testing?

- Shorter
- Targeting
- Computerized Algorithm

CAT in the Military

- Armed Services Vocational Aptitude Battery (ASVAB)

ARMY

CAT for Certification

CAT for Licensure

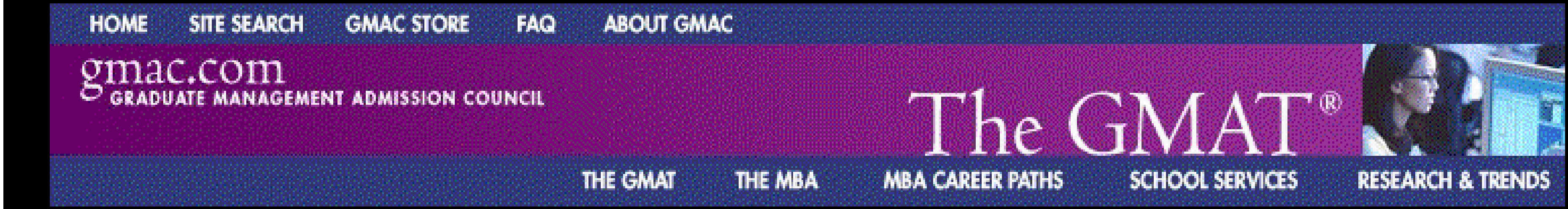
na
bp®

AMERICAN DIETETIC ASSOCIATION

NATIONAL
COUNCIL®

National Council
of State Boards of Nursing, Inc.

CAT for College Entrance



The College Board

ACCUPLACER OnLine

toefl.org

Test of English as a Foreign Language

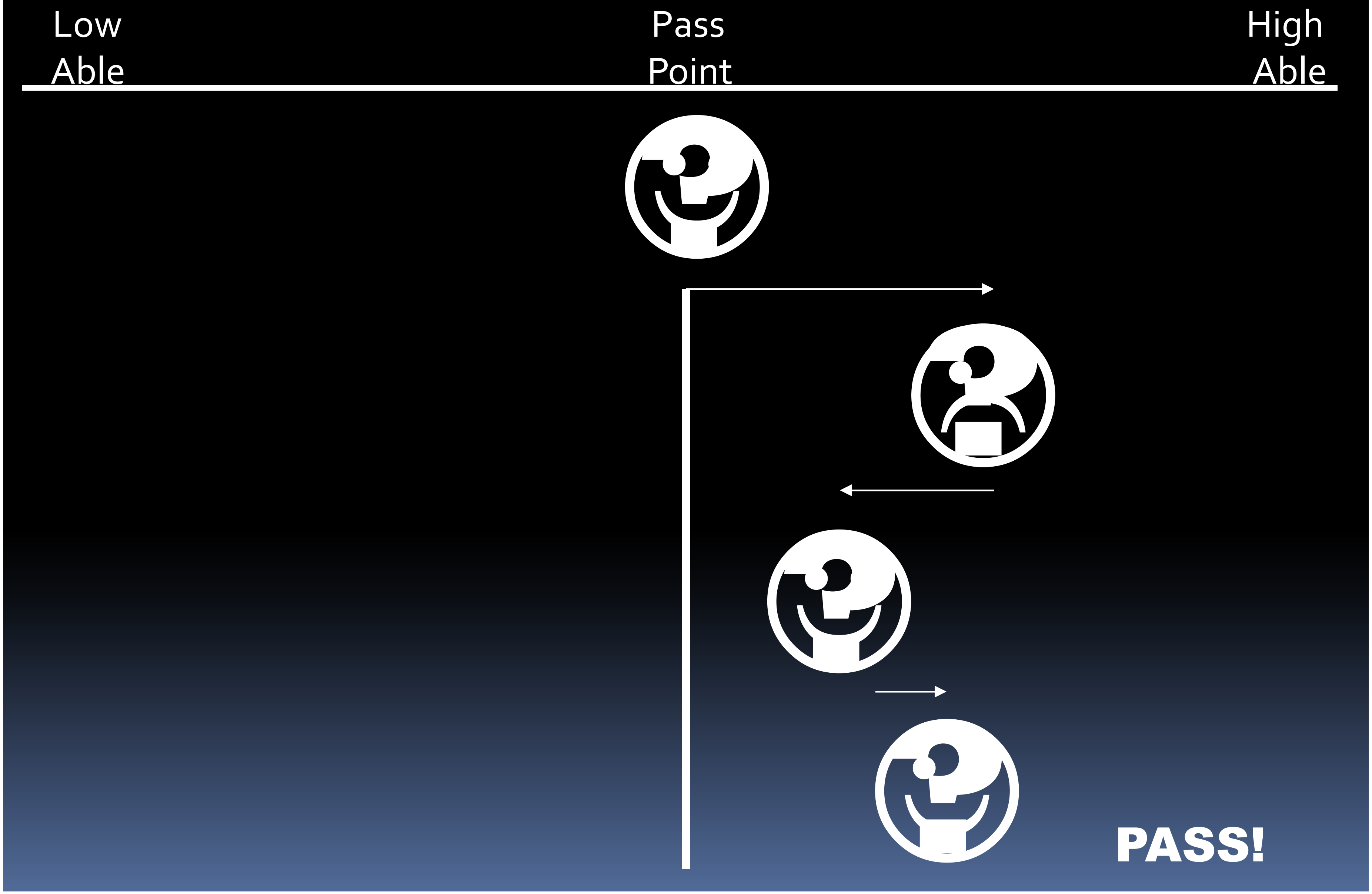
Graduate Record Examinations®

CAT for Education

Northwest Evaluation Association

IUPUI

Renaissance Learning™

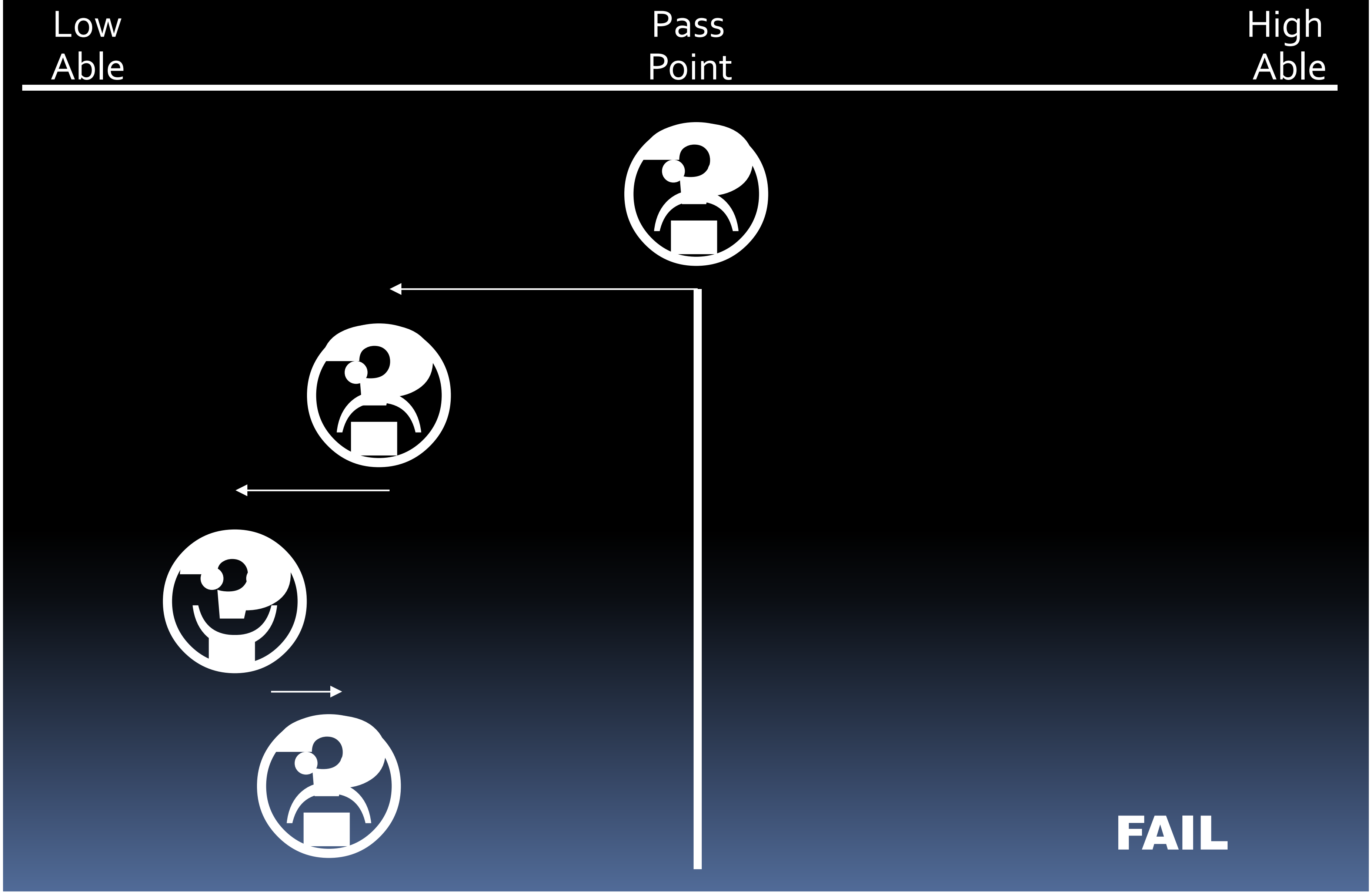


Low Able

Pass Point

High Able

PASS!



Low Able

Pass Point

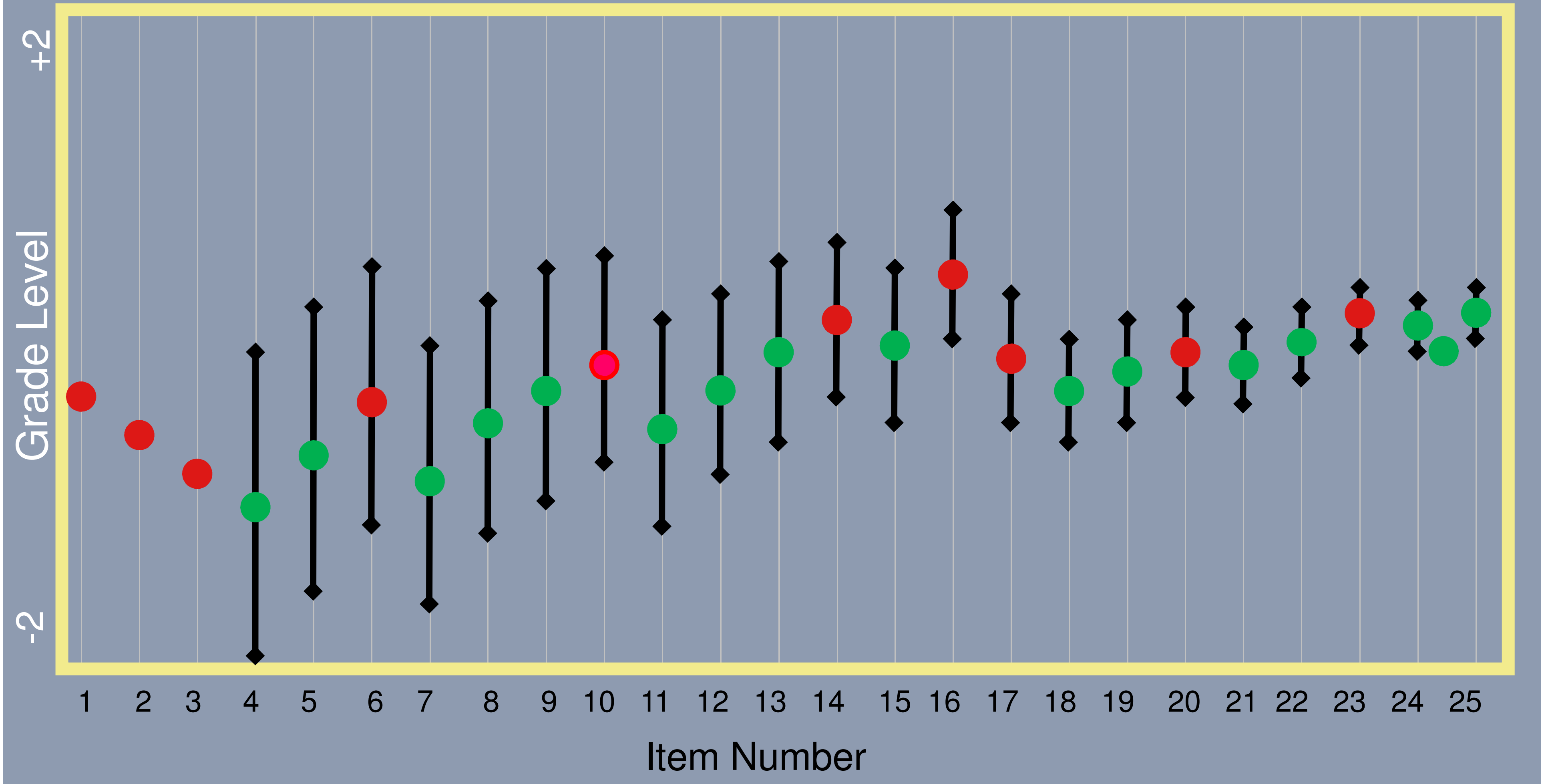
High Able

FAIL

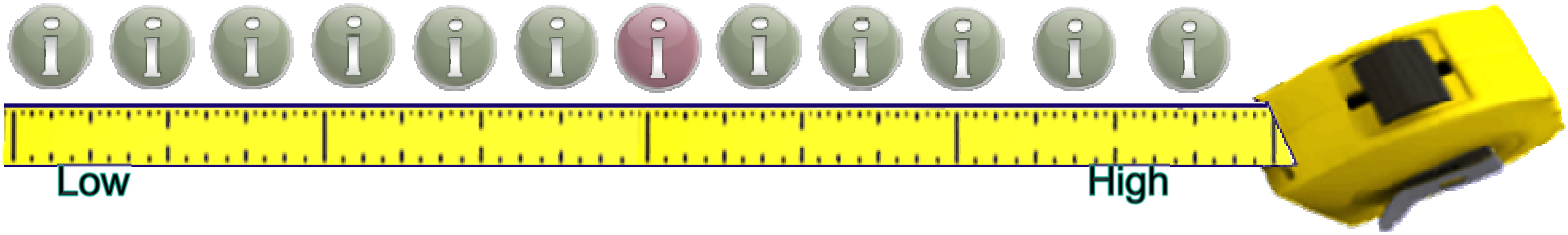
Example – Binary Search

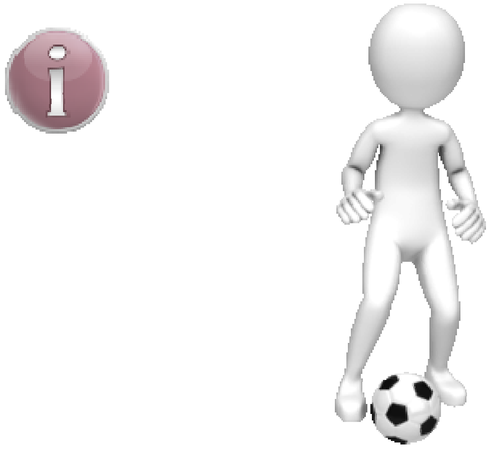
- Binary search

With each successive item, Standard error decreases

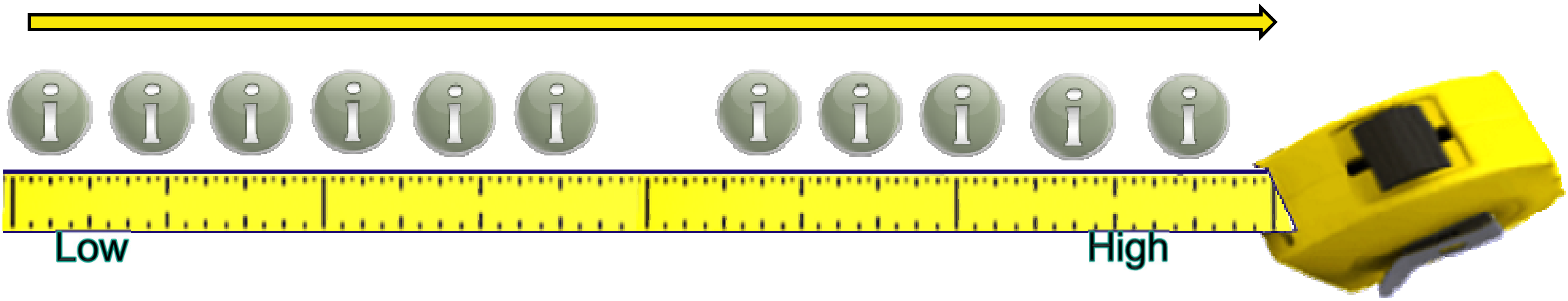


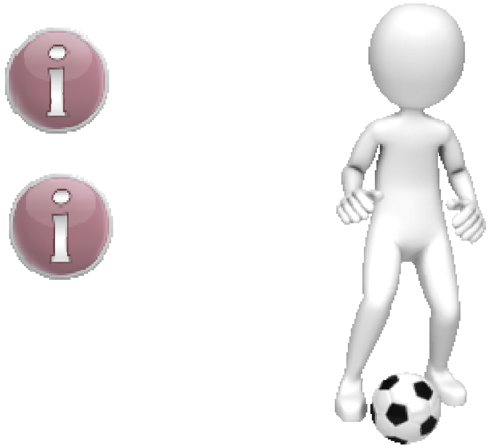
Physical Function

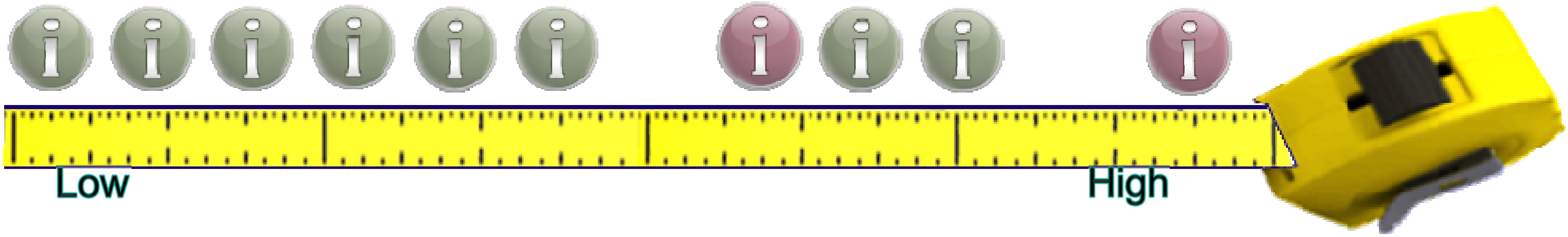

Low
High

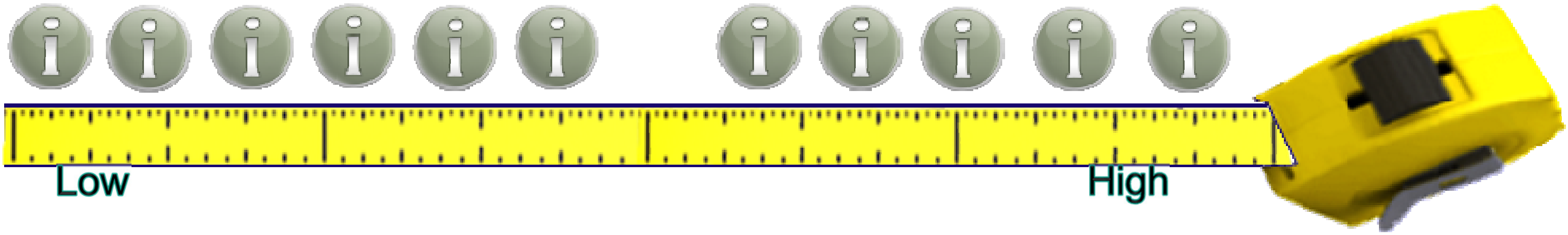


$$\ln L(u|\theta) =$$
$$\sum[u_i \ln P_i + (1\text{-}u_i) \ln Q_i$$



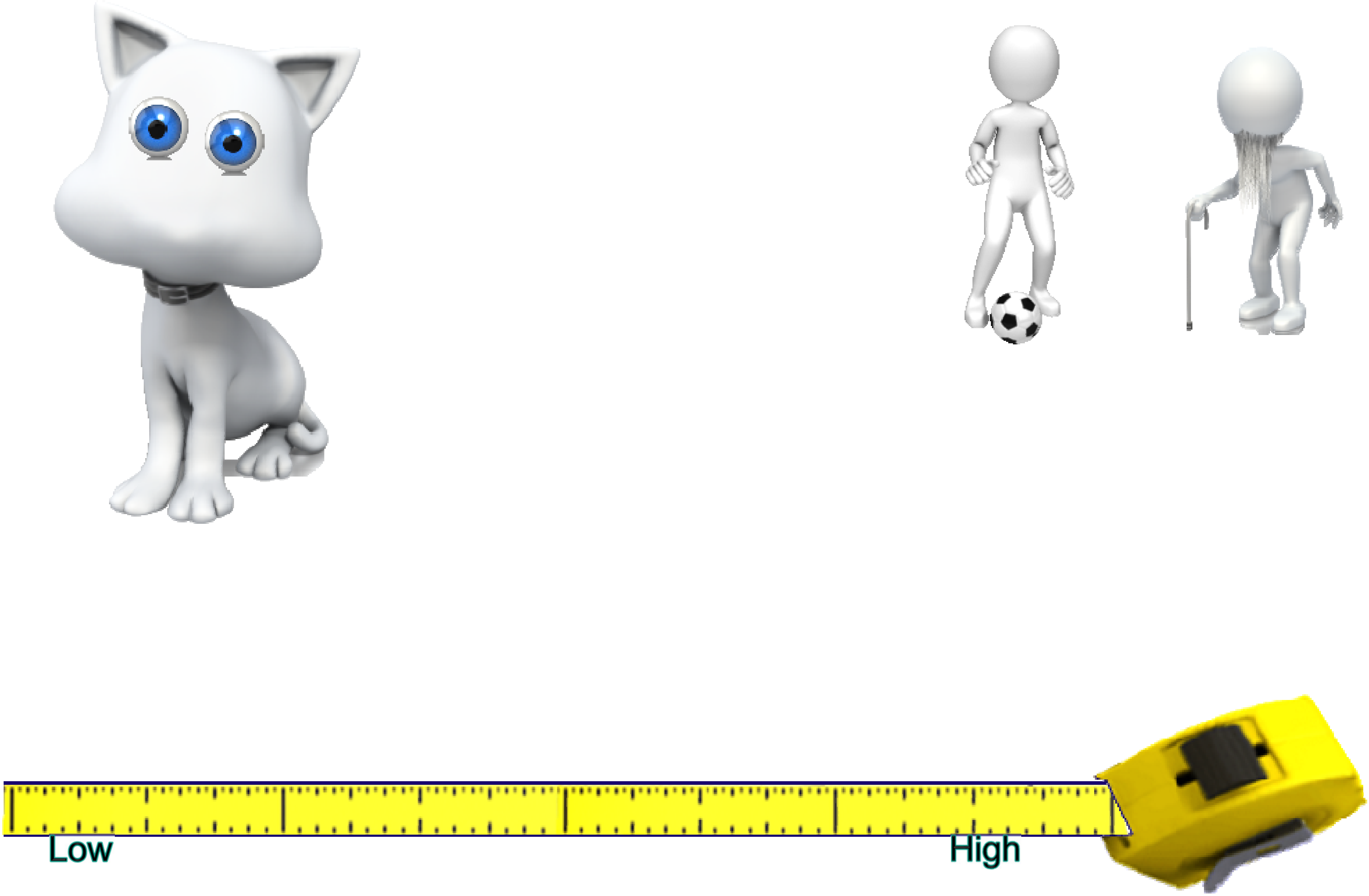



Low
High



Low

High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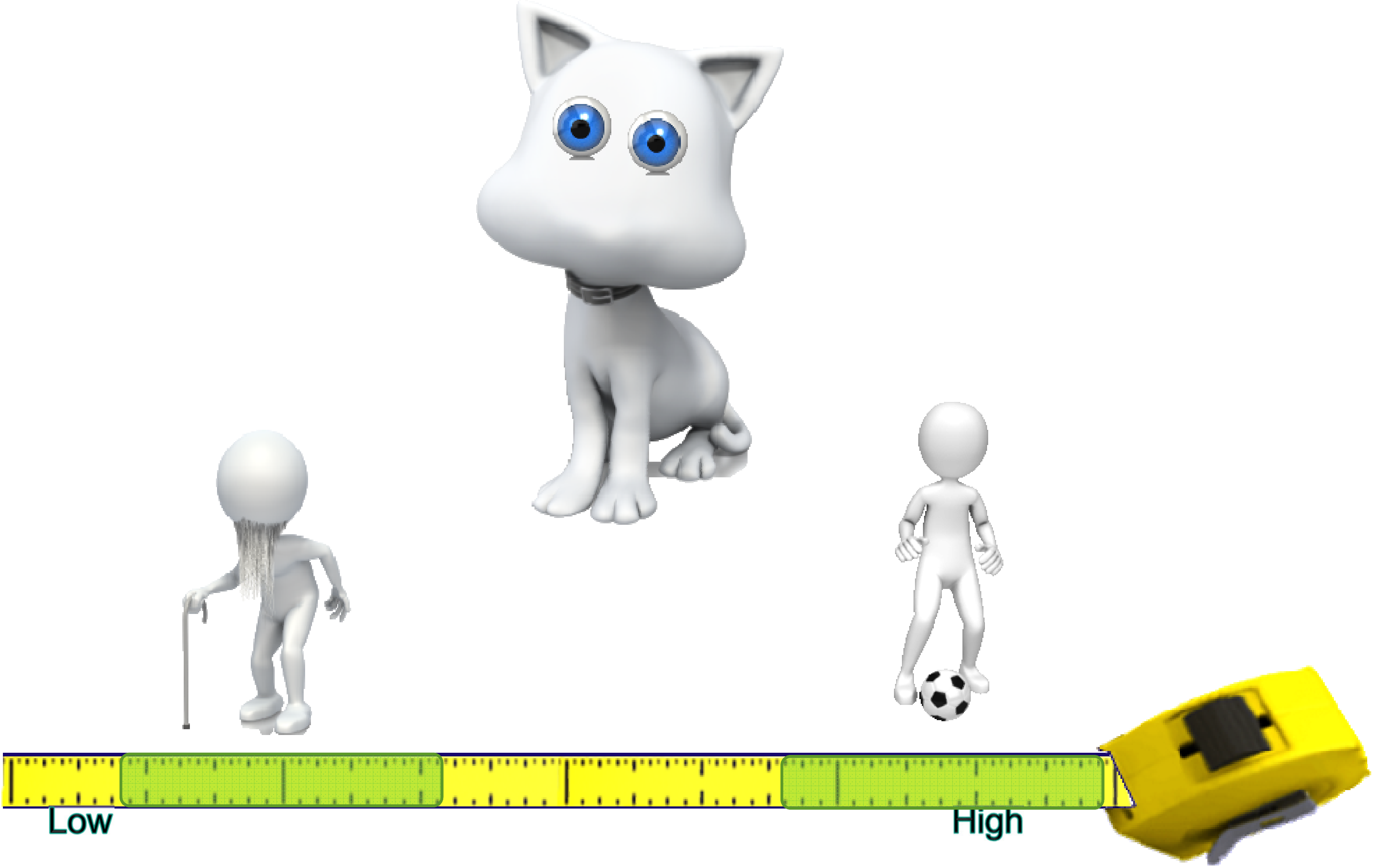
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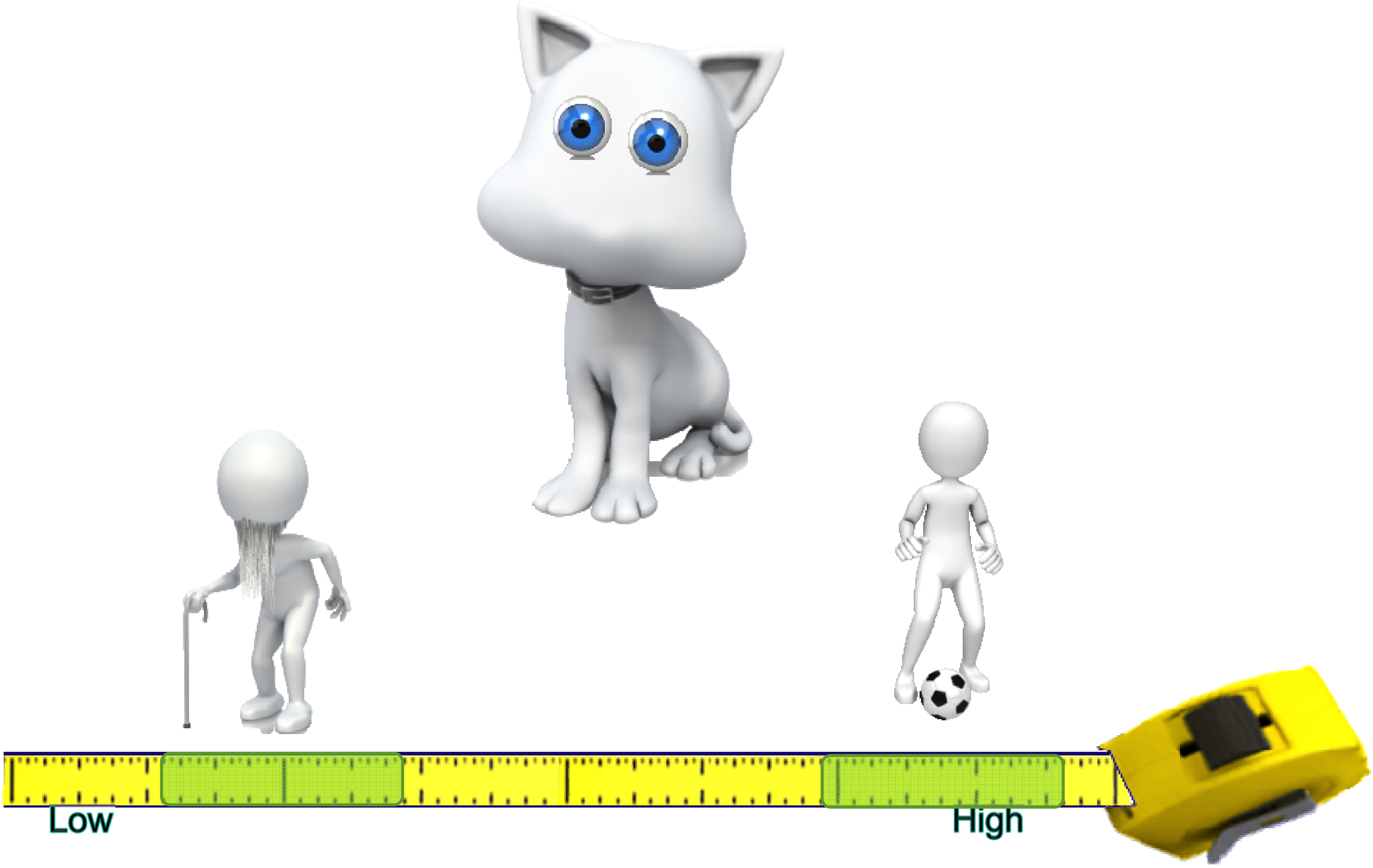
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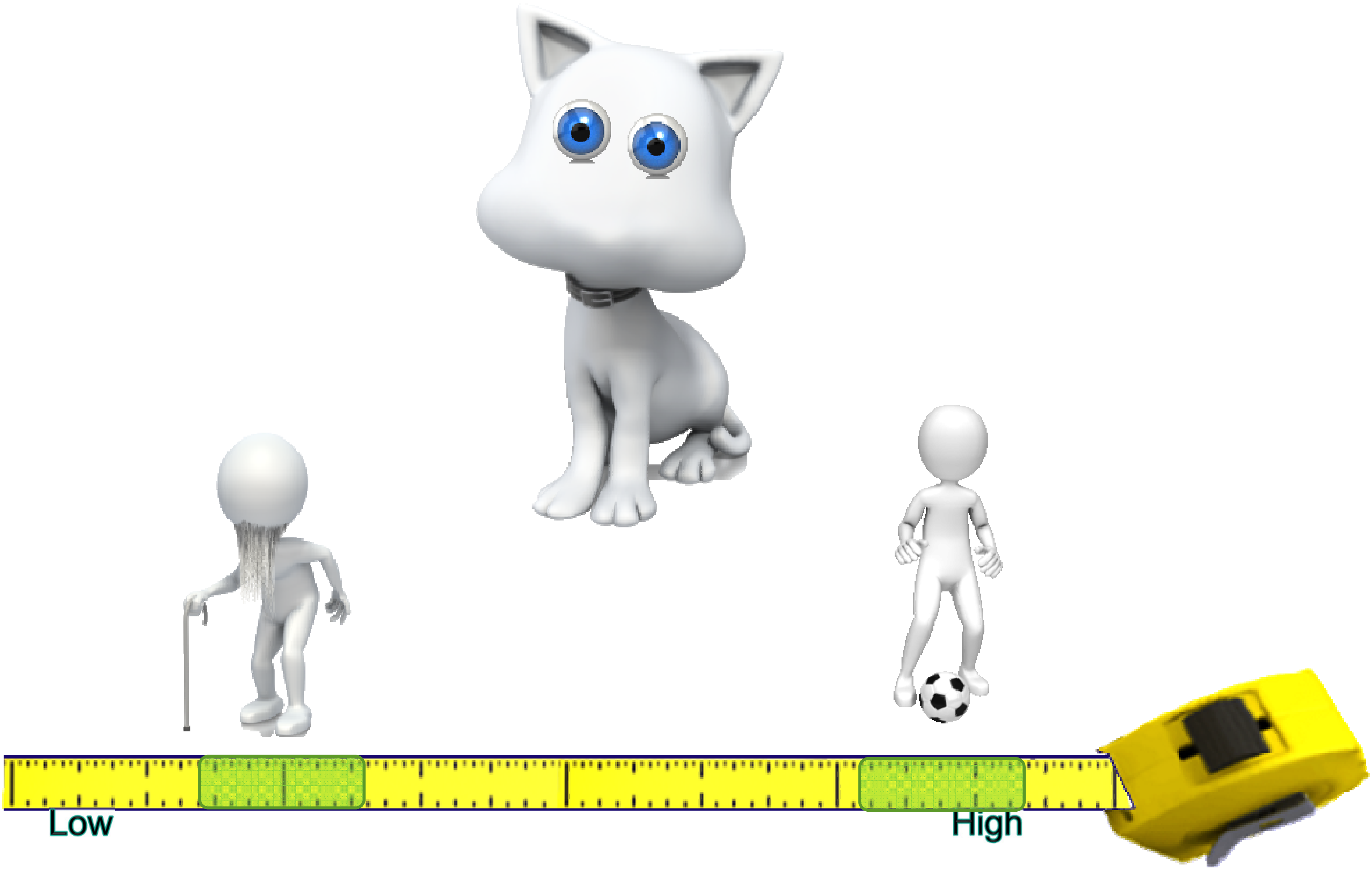
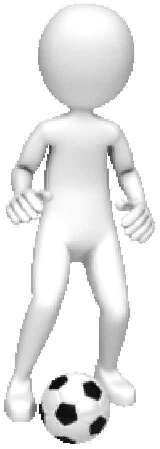
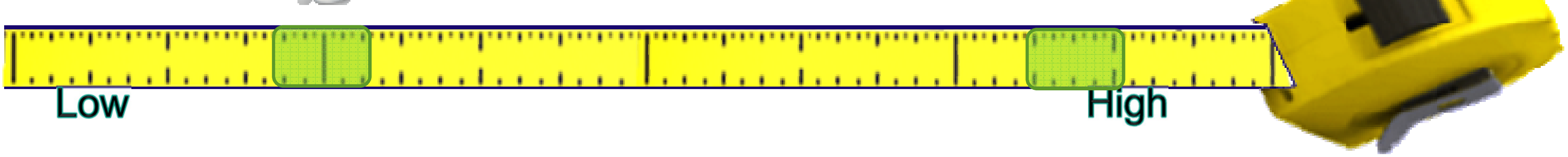
High


Low
High

Specified # of items

Specified level of precision





Why bother?

- ✓ Reduce burden of responding
- ✓ Make room for measuring more domains

CAT Requirements

- Calibrated item bank
- Administration software

Test Specifications

- Starting rule
- With item which provides maximum information
- At cut point

Test Specifications

- Stopping Rule
  - Fixed length
  - Variable length
  - By Total Test/Subtest
  - Calculated
    - Specified precision of measure
    - Specified confidence in a pass/fail decision
  - Maximum item count
  - Minimum item count

Adaptive Algorithm

- Person ability algorithm
- Item selection algorithm
  - Test difficulty
  - Maximum jump size
  - Content issues
  - Item exposure control
  - Option to not allow same items to be used during retesting
  - Overlapping items (items that cue other items)

Clear Pass

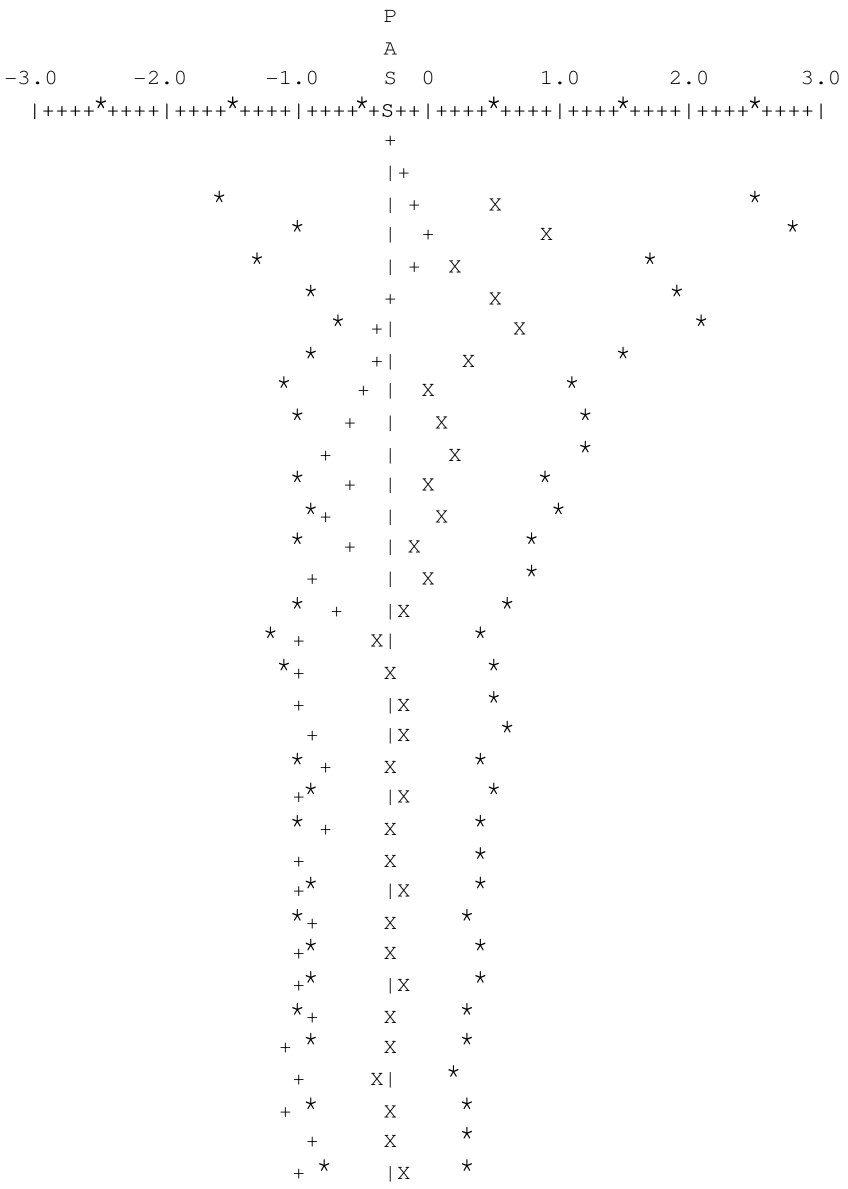
```
339585909     Entry= 1
MLT           Ver: 10/01/01

Tested:       01/28/02
Status:       2

                                                                                         P
                                                                                         A
                                                          -3.0      -2.0      -1.0       S0        1.0       2.0       3.0
Item      AN Cont   Diff Ans 🔔  =    Time  !   Meas    SE    |++++*++++|++++*++++|++++*+++S|++++*++++|++++*++++|++++*++++|
   1  21151  BBN  -0.09  1  1  o    2'30      9.99  9.99                                 +
   2  22805  CHE   0.03  2  1  o    2'56      9.99  9.99                                 |+
   3  22479  HEM   0.13  4  0  o    0'36      0.72  1.22                     *           | +     X                   *
   4  21986  MIC   0.13  3  1  o    0'29      1.15  1.15                          *      | +         X                  >
   5  22397  IMM   0.26  1  1  o    0'10      1.48  1.12                              *  |   +           X              >
   6  21793  UA    0.46  4  1  o    0' 9      1.76  1.10                                 |*    +            X           >
   7  22504  BBN   0.50  3  1  o    0'56      1.99  1.08                                 |  *  +              X         >
   8  22083  CHE   0.57  4  1  o    0'22      2.19  1.07                                 |    * +               X       >
   9  22641  HEM   0.74  4  1  o    0'59      2.38  1.06                                 |      *+                X     >
  10  20194  MIC   0.90  2  1  +    3'17      2.56  1.05                                 |        *+                X   >
  11  22032  BBN   1.00  4  0  o    1'26      1.92  0.78                                 |      *   +        X          >
  12  20344  CHE   1.00  4  1  o    1' 0      2.08  0.77                                 |        * +          X        >
  13  22261  HEM   1.12  4  0  o    1' 9      1.72  0.66                                 |      *    +     X          *
  14  21851  MIC   0.94  4  1  o    1'15      1.85  0.65                                 |        *+        X          *
  15  21511  IMM   1.02  1  1  o    2'14      1.97  0.65                                 |         *+         X         >
  16  21450  UA    1.27  1  1  +    1'17      2.09  0.64                                 |          *  +       X        >
  17  20537  BBN   0.93  3  1  o    0'35      2.18  0.64                                 |         + *          X       >
  18  22330  CHE   1.12  2  1  +    2'32      2.28  0.63                                 |           +*          X      >
  19  21218  HEM   1.02  1  1  o    0'37      2.36  0.63                                 |          +  *          X     >
  20  21628  MIC   0.96  3  1  o    1' 3      2.44  0.63                                 |          +   *         X     >
  21  22748  BBN   1.07  1  1  o    2'10      2.51  0.62                                 |           +   *         X    >
  22  22553  CHE   1.22  3  1  o    0'31      2.59  0.62                                 |            +   *         X   >
  23  22639  HEM   1.28  1  1  o    0'57      2.66  0.62                                 |             +  *          X  >
  24  22646  MIC   1.35  2  0  =    2'44      2.40  0.55                                 |             + *        X     >
  25  22663  IMM   1.27  1  0  o    1'17      2.19  0.50                                 |             +*       X       >
  26  22557  UA    1.06  2  1  o    0'41      2.25  0.50                                 |           +  *        X      >
  27  20686  BBN   1.15  1  1  o    0'27      2.31  0.50                                 |            +  *       X      >
  28  22634  CHE   1.37  3  0  o    1'19      2.15  0.46                                 |              +      X       *
  29  21646  HEM   1.16  2  1  o    0'15      2.20  0.46                                 |            + *       X       *
  30  22387  MIC   1.31  4  1  o    0'23      2.26  0.46                                 |             + *       X      >
  31  20018  BBN   1.27  3  1  o    0'34      2.31  0.45                                 |             +  *      X      >
  32  22059  CHE   1.40  1  1  o    0'48      2.37  0.45                                 |              + *       X     >
  33  22471  HEM   1.34  1  1  o    0'41      2.42  0.45                                 |             +   *      X     >
```

Clear Fail

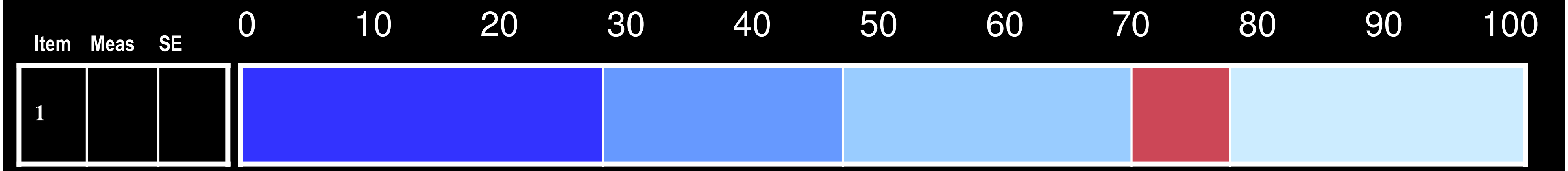
```
434843789     Entry= 1
HT            Ver: 01/01/02

Tested:       01/28/02
Status:       1

                                                                                             P
                                                                                             A
                                                          -3.0      -2.0      -1.0        0  S     1.0       2.0       3.0
Item     AN Cont   Diff Ans 🔔  =    Time  !   Meas    SE    |++++*++++|++++*++++|++++*++++|++S+*++++|++++*++++|++++*++++|
   1  31384  ST    0.35  1  0       0'34     -9.99  9.99                                     |+
   2  31009  FIX   0.22  3  1       0'18      0.29  1.41              *                     +X                     *
   3  31113  LO    0.18  1  0       0'26     -0.44  1.22         *                    X     +|            *
   4  30385  MIC   0.36  3  1       0'33      0.28  1.00                    *                X+             *
   5  30873  ST    0.24  3  0       0'31     -0.14  0.91                  *              X  +|         *
   6  30533  PRO   0.05  2  0       0'30     -0.46  0.87               *             X    +  |      *
   7  30525  ST    0.35  2  0       0'16     -0.67  0.84              *            X         |+  *
   8  31008  FIX   0.37  4  0       0'31     -0.83  0.82            *             X          |+*
   9  30664  ST    0.30  2  0       0'32     -0.98  0.80           *            X            +
  10  31086  LO    0.35  4  0       0'12     -1.11  0.79          *            X            *|+
  11  31626  ST    0.34  2  0       0'23     -1.22  0.78         *            X            * +
  12  31356  MIC   0.32  4  1       0'41     -0.81  0.67               *          X          +
  13  31210  PRO   0.21  2  0       0'35     -0.92  0.66              *          X          +|
  14  31148  ST    0.39  1  0       0'20     -1.01  0.65             *          X          * |+
  15  31620  FIX   0.25  4  0       0'10     -1.10  0.65            *          X          *  +
  16  30224  ST    0.20  4  0       0'25     -1.19  0.64            *         X          *  +|
  17  30940  FIX   0.40  2  0       0'32     -1.25  0.64           *         X          *    |+
  18  31288  ST    0.25  3  1       1'14     -0.97  0.57               *        X         *  +
  19  31529  LO    0.28  1  0       0'58     -1.04  0.56              *         X        *   +
  20  31120  ST    0.40  2  0       0'11     -1.10  0.56              *        X        *    |+
  21  31355  MIC   0.36  2  0       0'59     -1.15  0.56             *        X         *    |+
  22  31207  PRO   0.33  2  0       0'34     -1.21  0.55             *        X        *     +
  23  30745  ST    0.33  4  0       0'33     -1.26  0.55            *        X        *      +
  24  31285  FIX   0.40  3  0       0'13     -1.31  0.55            *        X        *      |+
  25  30237  ST    0.39  3  0       0'22     -1.35  0.55           *        X        *       |+
  26  30179  ST    0.26  1  0       0'24     -1.40  0.54           *        X        *       +
  27  31055  FIX   0.23  4  1       0'24     -1.18  0.50              *       X       *     +|
  28  31598  LO    0.29  2  0       0'33     -1.23  0.49              *       X       *      +
  29  30384  MIC   0.27  3  0       0'11     -1.27  0.49             *       X       *       +
  30  30524  ST    0.20  1  0       0'21     -1.31  0.49             *       X       *      +|
  31  31470  PRO   0.38  1  0       0'16     -1.35  0.49            *       X        *       |+
  32  30188  ST    0.31  3  0       0'21     -1.39  0.49            *       X       *        +
  33  31402  FIX   0.28  3  0       1' 9     -1.42  0.49            *       X       *        +
```

Fence Sitter

```
411433522     Entry= 1
PBT           Ver: 10/01/01

Tested:       01/26/02
Status:       1

Item     AN Cont   Diff Ans  🔔  =     Time  !    Meas    SE
   1  220576 SC   -0.33  3  1  o    0'37       9.99  9.99
   2  220304 LO   -0.24  2  1  o    1'13       9.99  9.99
   3  220935 SPH  -0.13  4  0  o    1' 3       0.46  1.22
   4  220213 SC   -0.03  1  1  +    0'52       0.92  1.15
   5  220378 AP   -0.11  3  0  =    0'40       0.24  0.91
   6  220523 SC   -0.30  4  1  o    0'10       0.50  0.87
   7  220611 LO   -0.37  2  1  o    0'17       0.70  0.84
   8  220928 SC   -0.38  1  0  o    0'33       0.27  0.73
   9  220218 SPH  -0.48  3  0  o    0'50      -0.04  0.67
  10  220975 SC   -0.65  3  1  o    0'46       0.10  0.65
  11  220709 SC   -0.79  1  1  o    0'35       0.21  0.63
  12  220634 LO   -0.56  2  0  =    0'41      -0.03  0.59
  13  220708 SPH  -0.81  1  1  o    0'22       0.07  0.57
  14  220748 SC   -0.65  2  0  o    0'34      -0.13  0.54
  15  220369 AP   -0.88  2  1  o    0'39      -0.04  0.53
  16  220777 SC   -0.68  1  0  o    0'40      -0.21  0.50
  17  220265 LO   -0.97  1  0  o    0'12      -0.37  0.49
  18  220885 SC   -0.95  1  1  o    0'33      -0.29  0.47
  19  220302 SPH  -0.98  2  1  o    0' 8      -0.22  0.46
  20  220044 SC   -0.88  1  1  o    0'32      -0.15  0.46
  21  220442 SC   -0.80  4  0  o    0'16      -0.28  0.44
  22  220263 LO   -1.01  1  1  o    0'52      -0.22  0.43
  23  220507 SPH  -0.79  1  0  o    0'30      -0.34  0.42
  24  220037 SC   -1.00  4  1  +    0'43      -0.28  0.41
  25  220317 AP   -1.05  3  1  o    0'11      -0.23  0.41
  26  220535 SC   -0.92  3  0  =    0'51      -0.33  0.40
  27  220987 LO   -1.02  4  1  o    0'25      -0.28  0.39
  28  220342 SC   -0.99  3  1  o    0'49      -0.23  0.39
  29  220089 SPH  -0.89  2  0  o    0'41      -0.33  0.38
  30  220860 SC   -1.11  2  1  o    0'20      -0.29  0.37
  31  220754 SC   -0.98  3  0  o    0'47      -0.38  0.36
  32  220610 LO   -1.08  3  1  o    0'23      -0.33  0.36
  33  220347 SPH  -0.91  1  1  o    0'49      -0.29  0.36
  34  220856 SC   -1.01  2  1  +    1' 2      -0.25  0.35
```



Simulate Measure = 48

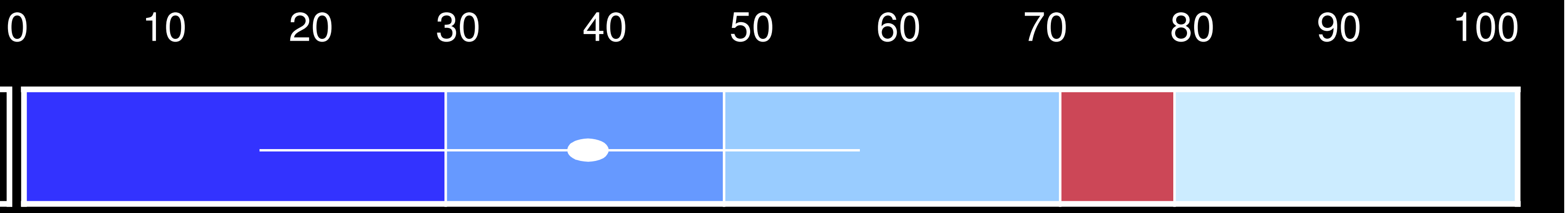


GP1 – I have a lack of energy

0= Very Much 1= Quite a Bit 2= Somewhat 3= A Little Bit 4= Not at All

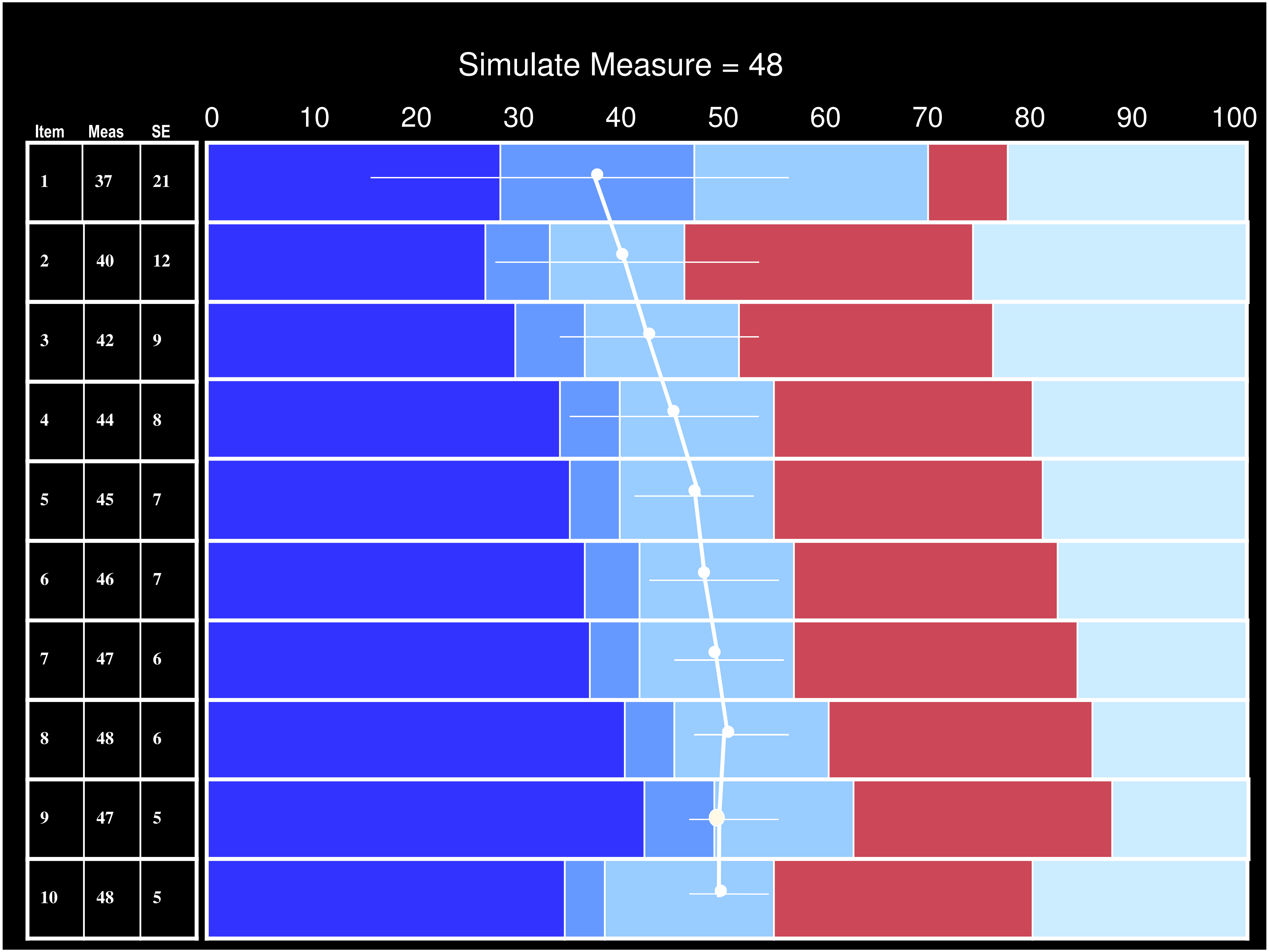
Simulate Measure = 48

Item	Meas	SE
1	37	21



GP1 – I have a lack of energy

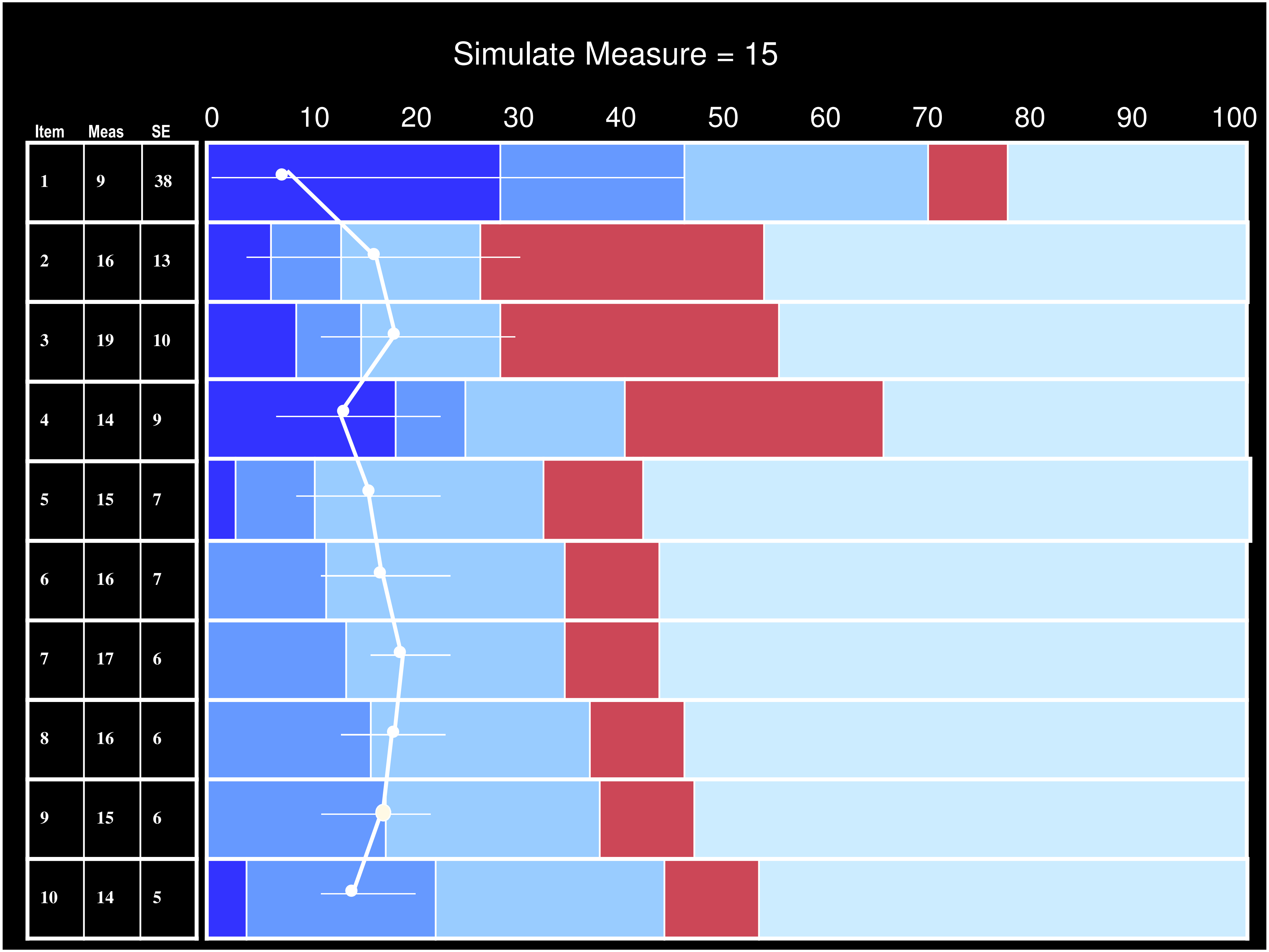
0 = Very Much; 1 = Quite a Bit; 2 = Somewhat; 3 = A Little Bit; 4 = Not at All



Simulate Measure = 48

Item	Meas	SE
1	37	21
2	40	12
3	42	9
4	44	8
5	45	7
6	46	7
7	47	6
8	48	6
9	47	5
10	48	5

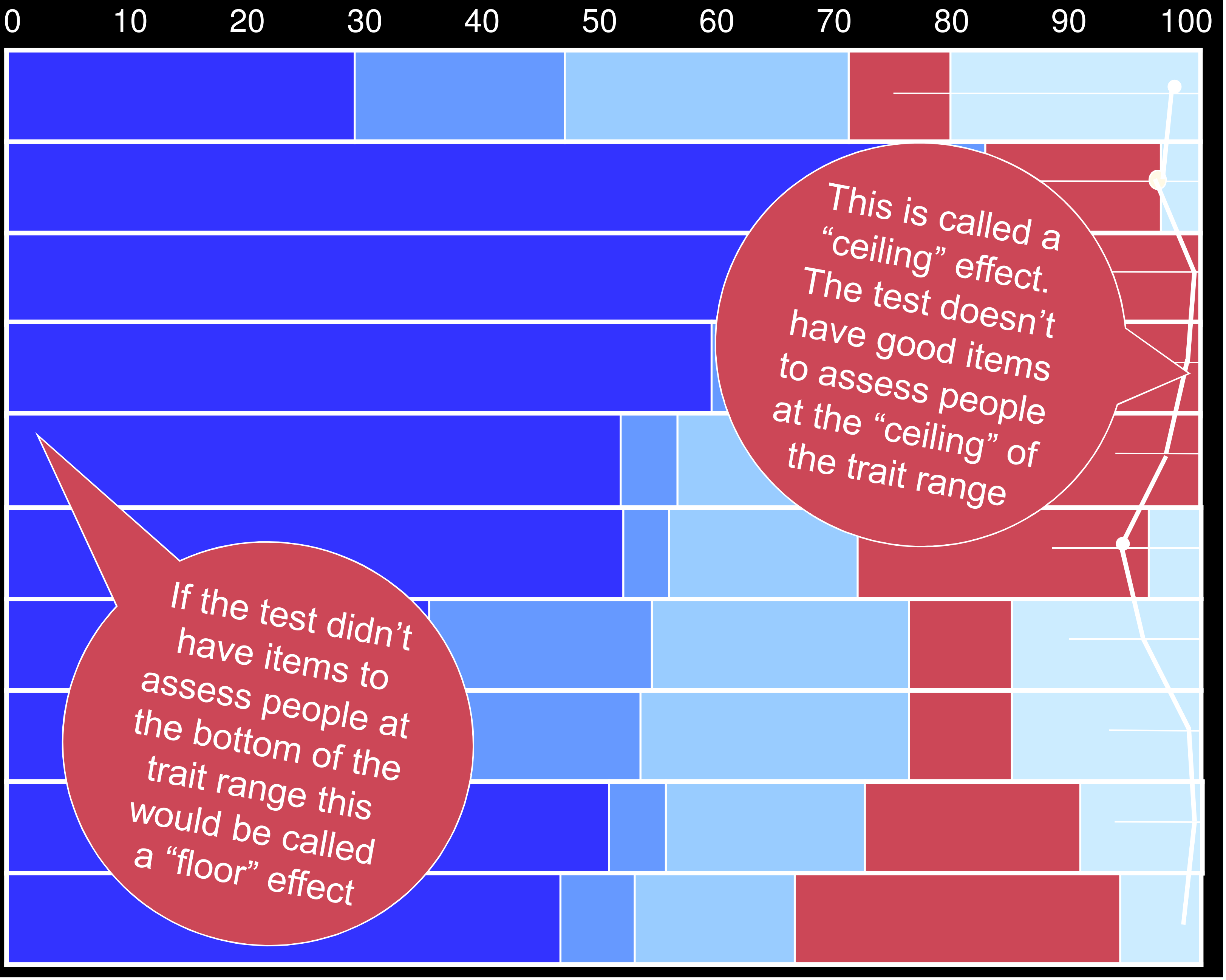
Simulate Measure = 15



Item	Meas	SE
1	9	38
2	16	13
3	19	10
4	14	9
5	15	7
6	16	7
7	17	6
8	16	6
9	15	6
10	14	5

Simulate Measure = 92

Item	Meas	SE
1	100	25
2	97	15
3	100	12
4	99	10
5	97	9
6	95	8
7	97	8
8	99	8
9	100	7
10	99	7



This is called a "ceiling" effect. The test doesn't have good items to assess people at the "ceiling" of the trait range

If the test didn't have items to assess people at the bottom of the trait range this would be called a "floor" effect