

Implementation of Cognitive Load Theory into Electronic Homework Assignments

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Outline of Presentation

- Description of Item Response Theory (IRT)
- How we used IRT in CHEM 1211/1212 at UGA
- Identification of 11 Consistently Difficult Topics for UGA students
- Interventions to Help Students
- Implementing Cognitive Load Theory into Homework
- Can we show improvement over time?
- Conclusions



Quick Description of Item Response Theory (IRT)

- Classical Test Theory (CTT)
 - Mean, median, mode
 - Discrimination Index
 - comparison of top and bottom quartiles
 - CTT is good for small samples
 - CTT is more dependent upon the subject group
 - Same assessment given to 2 groups will give different results



Quick Description of Item Response Theory (IRT)

- Item Response Theory (IRT)
 - More modern psychometric analysis tool than CTT
 - Works well for large sample sizes (> 200)
 - Iterative process which fits the students responses to a mathematical formula

$$P(\theta) = c + (1 - c) \frac{1}{1 + e^{-a(\theta - b)}}$$

θ = student ability level

a = discrimination parameter

b = item difficulty parameter

c = guessing parameter



Quick Description of Item Response Theory (IRT)

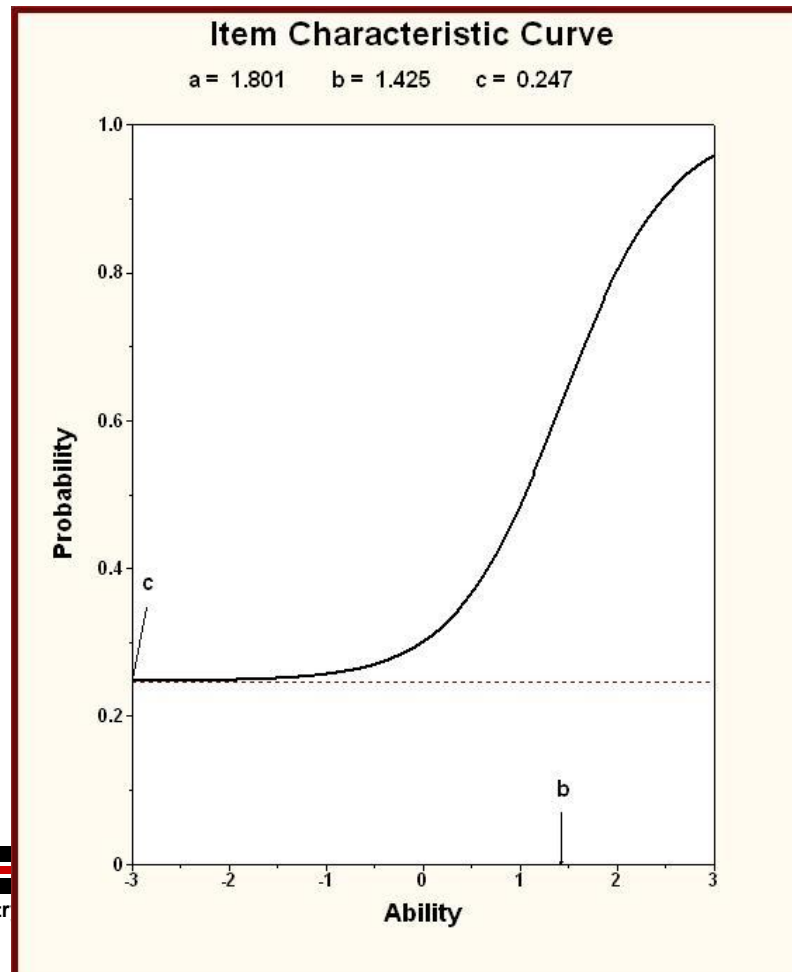
- We use the program Bilog-MG3 to fit our data.
- Bilog-MG3 assigns to every test item values for a, b, and c and displays them on an item characteristic curve
 - Plot of the probability of a student with a given IRT ability vs. probability that the student answered the question

$$P(\theta) = \frac{(1 + c)}{2}$$



Quick Description of Item Response Theory (IRT)

- Item Characteristic Curve



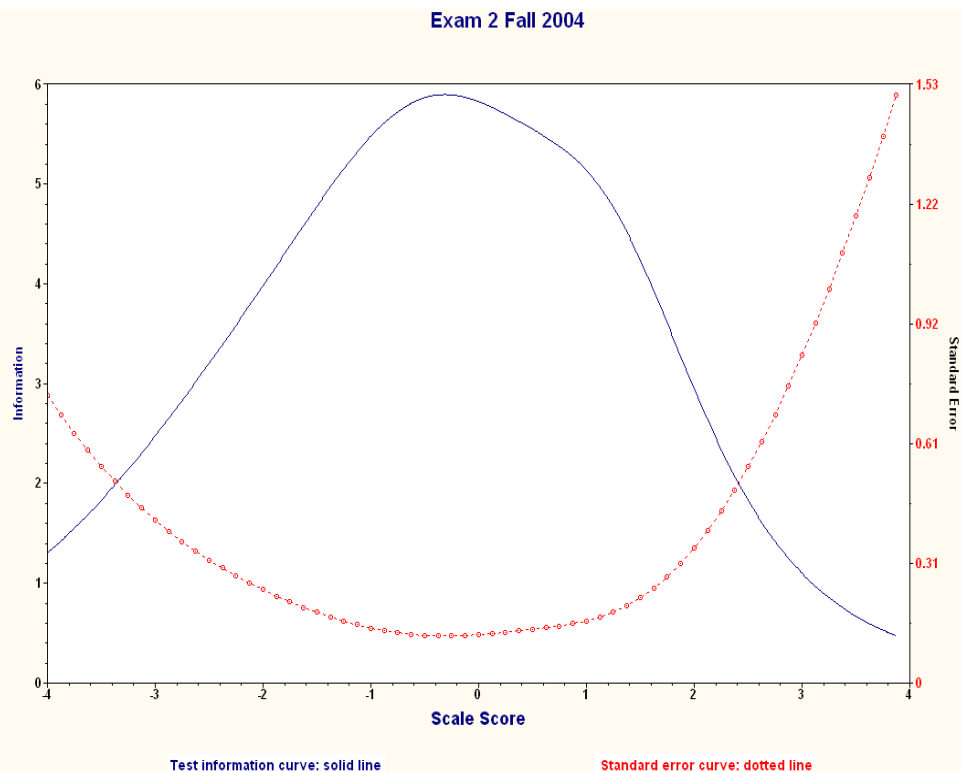
Identification of 11 Consistently Difficult Topics for UGA Students

- Because we give our tests via computer, we have 9 (going on 10) years of data stored on the server.
 - Kim Schurmeier analyzed the old test data
 - Chose the highly discriminating test questions with a variety of abilities
 - Built all of the 2005-2006 and succeeding tests based upon IRT analysis
 - Ideally the tests have
 - » 2 or 3 A-B discriminating questions
 - » 2 or 3 B-C discriminating questions
 - » 3 or 4 C-D discriminating questions
 - » Etc.



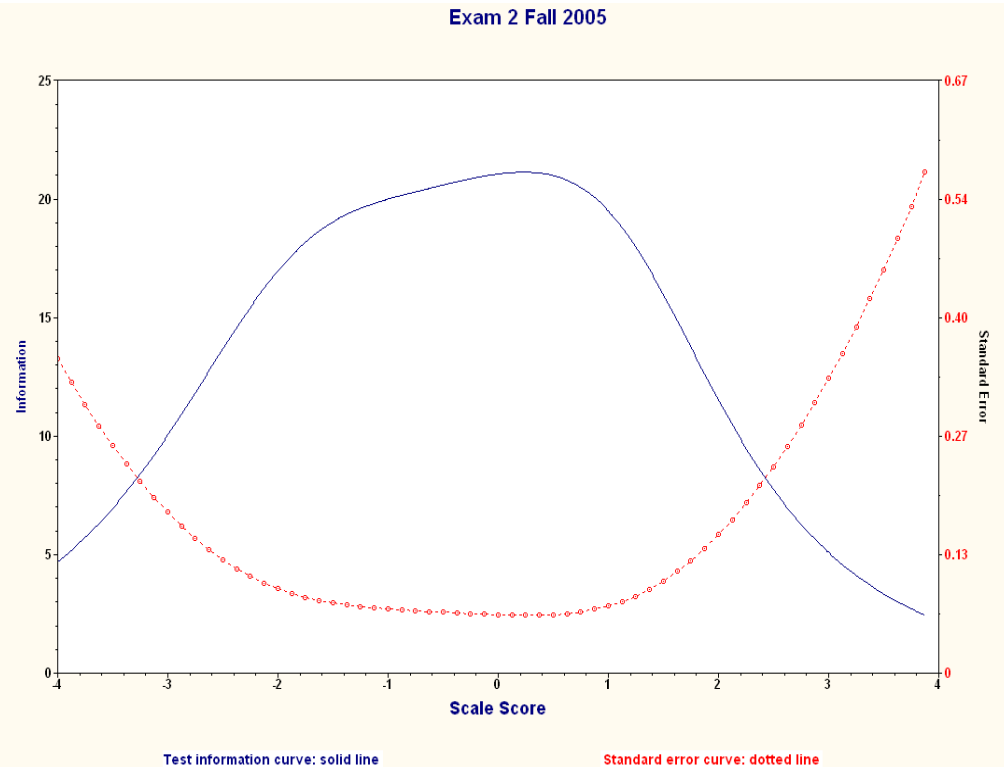
How we have used IRT in CHEM 1211/1212 at UGA

- Can tell us whether or not our tests are effectively assessing students at every ability level.
- Test information curve
 - Prior to IRT



How we have used IRT in CHEM 1211/1212 at UGA

- Test information curve
 - After IRT



Identification of 11 Consistently Difficult Topics for UGA Students

A key concept for our students:

Fall 2005 Test 1

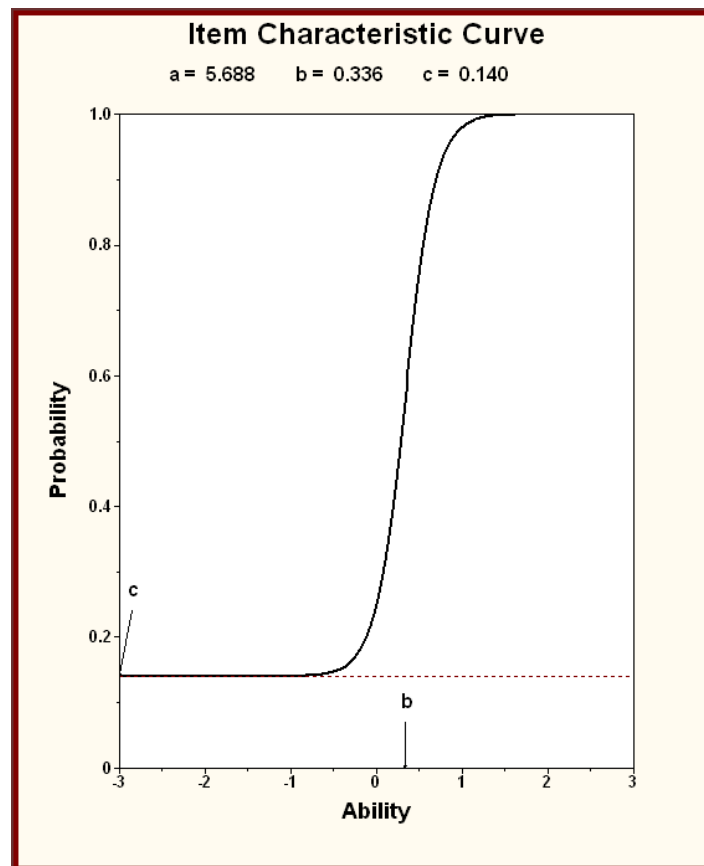
Question:

“What is the correct name of this ionic compound?” $\text{Al}(\text{NO}_3)_3$

aluminum nitrate

“How many ions are present in one formula unit of the compound shown above?”

4



Ability at 0.336

Discriminates between C and D students



Identification of 11 Consistently Difficult Topics for UGA Students

- Understanding the structure of ionic compounds is crucial to student performance in our Freshman Chemistry course.
- This concept is essentially a gatekeeper.
 - For our students getting them to grasp the concept of the particulate nature of matter is essential to their success.

Gabel, D. L., *J. Chem. Educ.* **1999**, 76, 548-554.

Johnstone, A. H., *J. Comp. Assist. Learn.* **1991**, 7, 701-703.



Identification of 11 Consistently Difficult Topics for UGA Students

- A second key concept/misconception

Match each property with the substances in the choose box that have the property. There is only one correct answer per property.

Students can choose from these options

HCl

HF

CH₃OH

HCl and HF

HCl, HF, and CH₃OH



Identification of 11 Consistently Difficult Topics for UGA Students

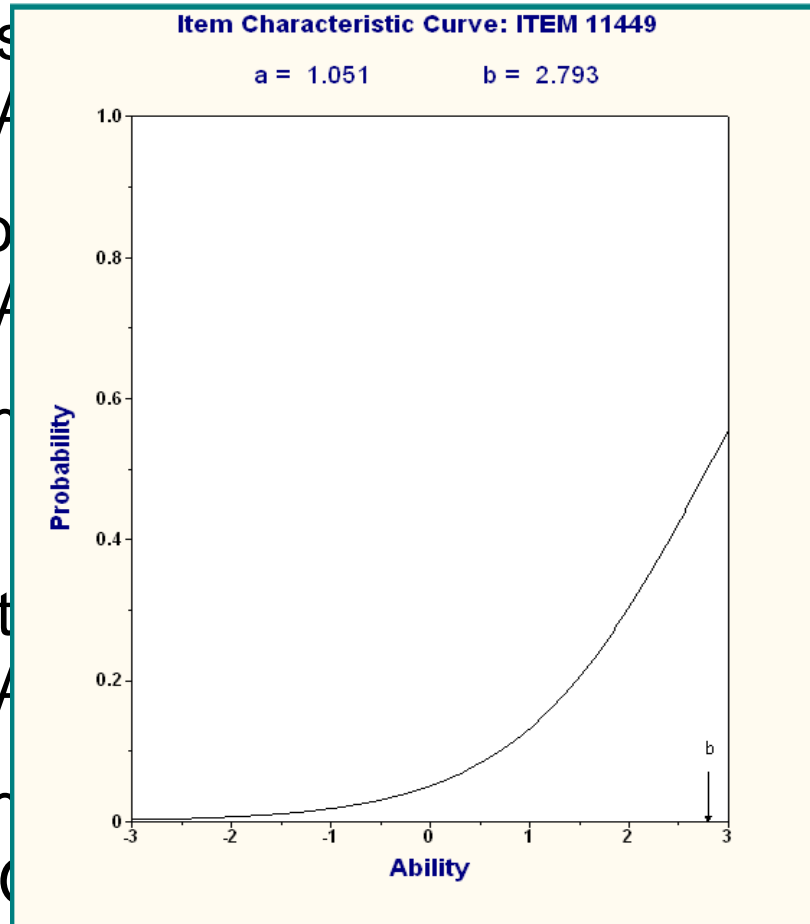
Conducts
Choose A

Ionizes o
Choose A

Can form
HCl, HF,

Does not
Choose A

Can form
and CH_3C



ous solutions.

solutions.

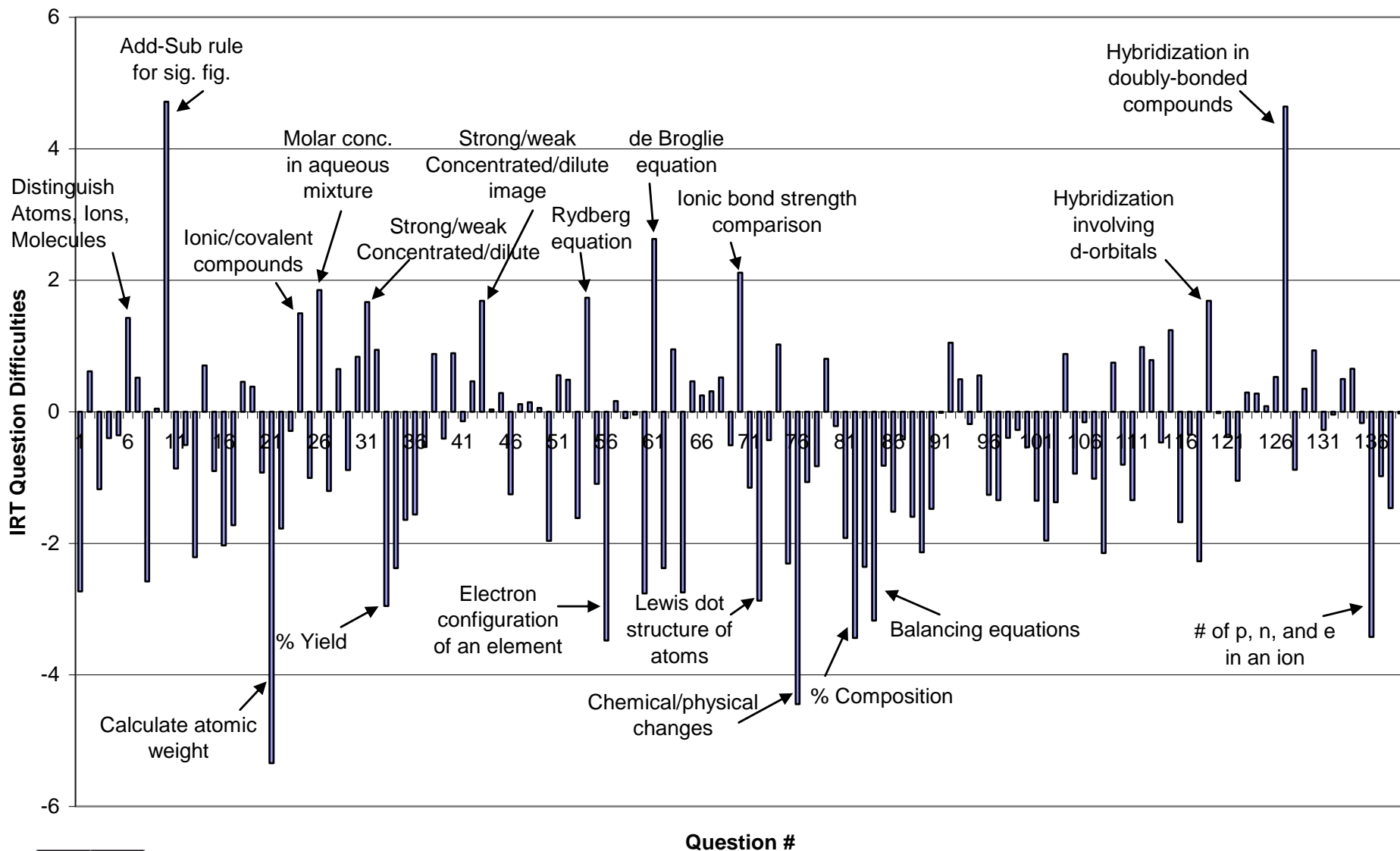
Choose Answer:

is solutions.

swer: HCl, HF,



1211 Fall 2008 IRT Question Difficulties



Identification of 11 Consistently Difficult Topics for UGA Students

- After Spring Semester 2006 and all subsequent semesters, we looked at those test questions having the highest discrimination and ability levels.
- This analysis showed that there are several topics which consistently cause students difficulty every year.



Identification of 11 Consistently Difficult Topics for UGA Students

- 1. Understanding the Particulate Nature of Matter**
Particularly compounds containing polyatomic ions and molecular representations of physical/chemical changes
- 2. Unit Conversions**
Nonlinear units
- 3. Molecular Shape and Polarity**
- 4. Ionic vs. Covalent, Strong/Weak, Concentrated/Dilute**
- 5. Understanding the physical meaning of quantum numbers**
What do n , l , m_l and m_s mean and indicate about atomic structure?
How the rules for quantum numbers are interrelated?
- 6. Limiting reactant calculations**
Mainly excess reactant

K.D. Schurmeier, C.G. Shepler, G.J. Lautenschlager, and C.H. Atwood, "Using Item Response Theory to Identify and Address Difficult Topics in General Chemistry", *Investigating Classroom Myths through Research on Teaching and Learning*, Chapter 10, 2011, pp 137-176 *ACS Symposium Series*, Volume 1074
Publication Date (Web): January 1, 2011 (Chapter).



Identification of 11 Consistently Difficult Topics for UGA Students

7. Lewis acids and bases

Concept of electron motion in reactions

8. Intermolecular forces

Vapor pressure, boiling and melting points based upon molecular structure

Another form of confusion over polarity and molecular shapes

9. Colligative properties

Effect of electrolytes on colligative properties

Another form of confusion over particulate nature of matter

10. Moles of reaction

Thermochemical equations

11. Percent dissociation

Algebra mistake based on misunderstanding of particulate nature of matter

Schraw, G., Brooks, D. W. and Crippen, K. J. *J. Chem. Educ.* **2005**

The Unified Learning Model: How Motivational, Cognitive, and Neurobiological Sciences Inform Best Teaching Practices, Shell D. F., Brooks D. W., Trainin, G., Springer, **2009**.



Interventions to Help Students

- Homework problems can identify “at risk” students prior to test time
- Derek Behmke has identified a trigger that reliably predicts which students need interventions
- Upon homework completion “at risk” students were sent an e-mail
- We could see improvements for students who attended but attendance rate was <15% of those invited



Cognitive Load Theory Implementation in Homework

- Human memory consists of long-term and short-term
 - Long-term is infinite in capacity
 - Short-term can handle at most 5 to 7 bits of information
- Cognitive load theory attempts to find ways to maximize transfer from short to long-term memory

Derek A. Behmke and Charles H. Atwood, "Implementation and Assessment of Cognitive Load Theory (CLT) Based Questions in an Electronic Homework and Testing System" in preparation for submission to the *International Journal of Science Education*.



Cognitive Load Theory

Implementation in Homework

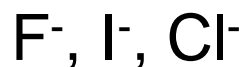
- Load can be further subdivided
- Intrinsic – load that is a result of the subject matter
 - Chemistry has lots of intrinsic load
- Extraneous – load due to how the subject is presented
 - Material that detracts from learning
- Germane – load that is essential to learn the material
 - Most important path to improve learning is to minimize extraneous and maximize germane



Cognitive Load Theory

Implementation in Homework

- Derek Behmke's approach to this was to build a series of homework questions that step by step increased the extraneous load
- Original homework question
 - Rank the following in order of increasing (weakest to strongest) conjugate base strength.



Worked Out Example (Question 1):

Question: Rank the following in order of increasing (weakest to strongest) conjugate base strength.
 F^- , I^- , Cl^-

Solution Step 1: We do not know how to arrange bases by strength directly, so must determine the conjugate acid of each base. This done by adding an H^+ to each base. The conjugate acid of each base is listed below.

The conjugate acid of F^- is HF

The conjugate acid of I^- is HI

The conjugate acid of Cl^- is HCl

Step 2: We must now arrange the conjugate acids in order of increasing acid strength. Since all of the acids listed above are binary they are ranked in strength based on the size of their anions. The smaller the anion the stronger the acid. Each anion has a parent element that you can find on the periodic table. The closer to the bottom and further left on the periodic table that parent element is, the larger it is. We must first identify what the anion is in each acid, and what period its parent element is located in on the periodic table. We do not have to worry about the group number because all of the parent elements of these anions are in the same in group on the periodic table. The correct ranking of the conjugate acids in order of increasing acid strength is shown below.

$HF < HCl < HI$

Step 3: We know that the stronger the acid the weaker its conjugate base, and the weaker an acid the stronger its conjugate base. In other words the strongest acid has the weakest conjugate base, and the weakest acid has the strongest conjugate base. Below is the correct ranking, in increasing order, of the conjugate bases listed above.

$I^- < Cl^- < F^-$



Question 2:

Question: Rank the following in order of increasing (weakest to strongest) conjugate base strength.
 OH^- , HTe^- , HS^-

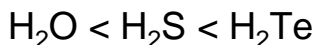
Solution Step 1: We do not know how to arrange bases by strength directly, so must determine the conjugate acid of each base. This done by adding an H^+ to each base. The conjugate acid of each base is listed below.

The conjugate acid of OH^- is H_2O

The conjugate acid of HTe^- is H_2Te

The conjugate base of HS^- is H_2S

Step 2: We must now arrange the conjugate acids in order of increasing acid strength. Since all of the acids listed above are binary they are ranked in strength based on the size of their anions. The smaller the anion the stronger the acid. Each anion has a parent element that you can find on the periodic table. The closer to the bottom and further left on the periodic table that parent element is, the larger it is. We must first identify what the anion is in each acid, and what period its parent element is located in on the periodic table. We do not have to worry about the group number because all of the parent elements of these anions are in the same in group on the periodic table. The correct ranking of the conjugate acids in order of increasing acid strength is shown below.



Student Responsibility: Rank the conjugate bases in the example above in order of increasing (weakest to strongest) conjugate base strength.



Question 3:

Question: Rank the following in order of increasing (weakest to strongest) conjugate base strength.
 OH^- , HTe^- , HSe^-

Solution Step 1: We do not know how to arrange bases by strength directly, so must determine the conjugate acid of each base. This done by adding an H^+ to each base. The conjugate acid of each base is listed below.

The conjugate acid of OH^- is H_2O

The conjugate acid of HTe^- is H_2Te

The conjugate acid of HSe^- is H_2Se

Student Responsibility: Rank the conjugate acids from the example above in order of increasing acid strength. Rank the conjugate bases in the example above in order of increasing (weakest to strongest) conjugate base strength.



Cognitive Load Theory Implementation in Homework

Topic #	Semester	Topic
1	1	Number of ions per formula unit
2	1	Complex dilution calculations
3	1	Interpreting first ionization energy
4	1	Inorganic nomenclature
5	2	Acid and base strength
6	2	Unit cell calculations
7	2	Interpreting vapor pressure lowering
8	2	Interpreting images to determine when equilibrium was established

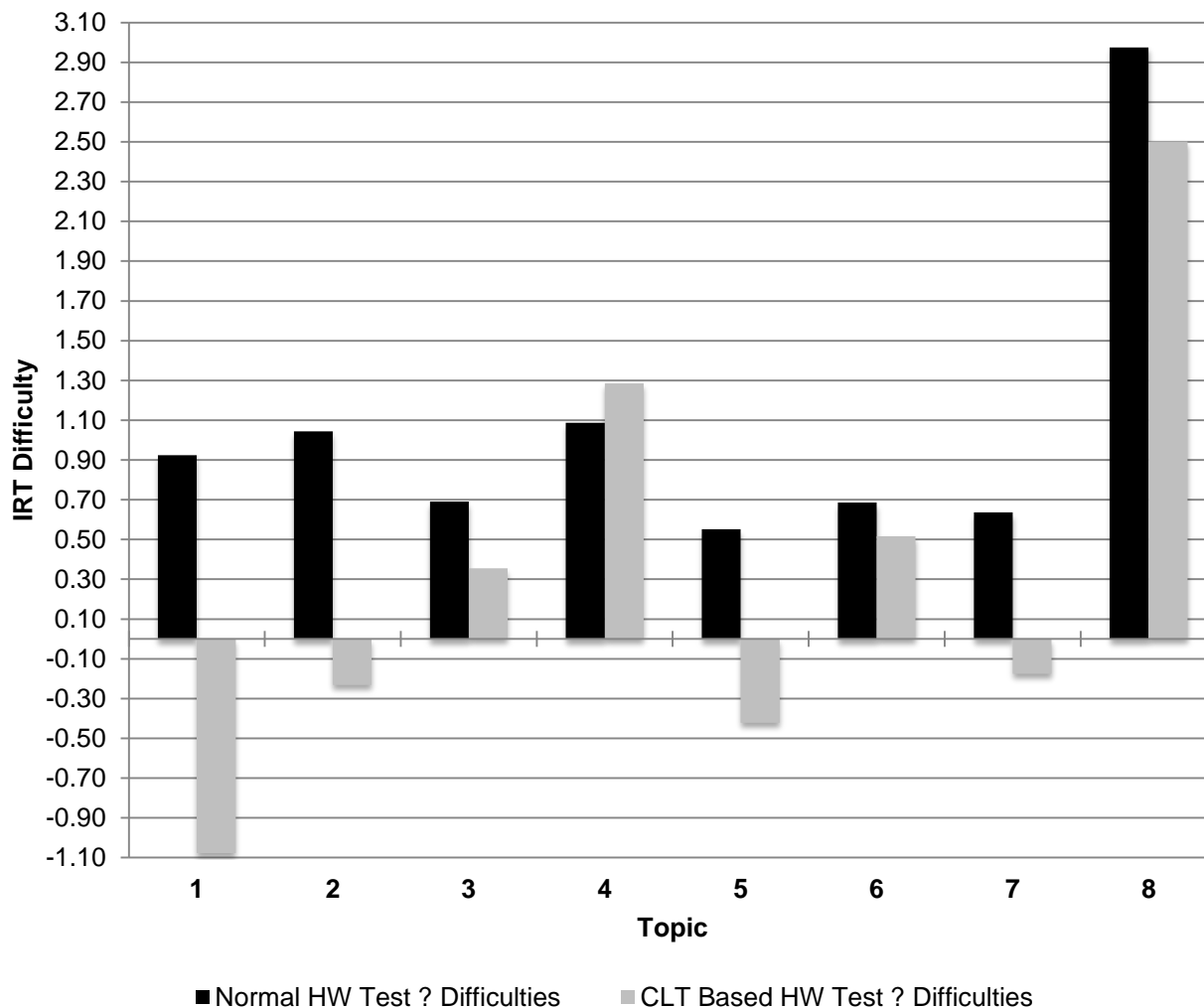


Cognitive Load Theory Implementation in Homework

- Tested students on these topics before and after CLT implementation



Test Question IRT Difficulties Before and After CLT Based Instructional Innovation



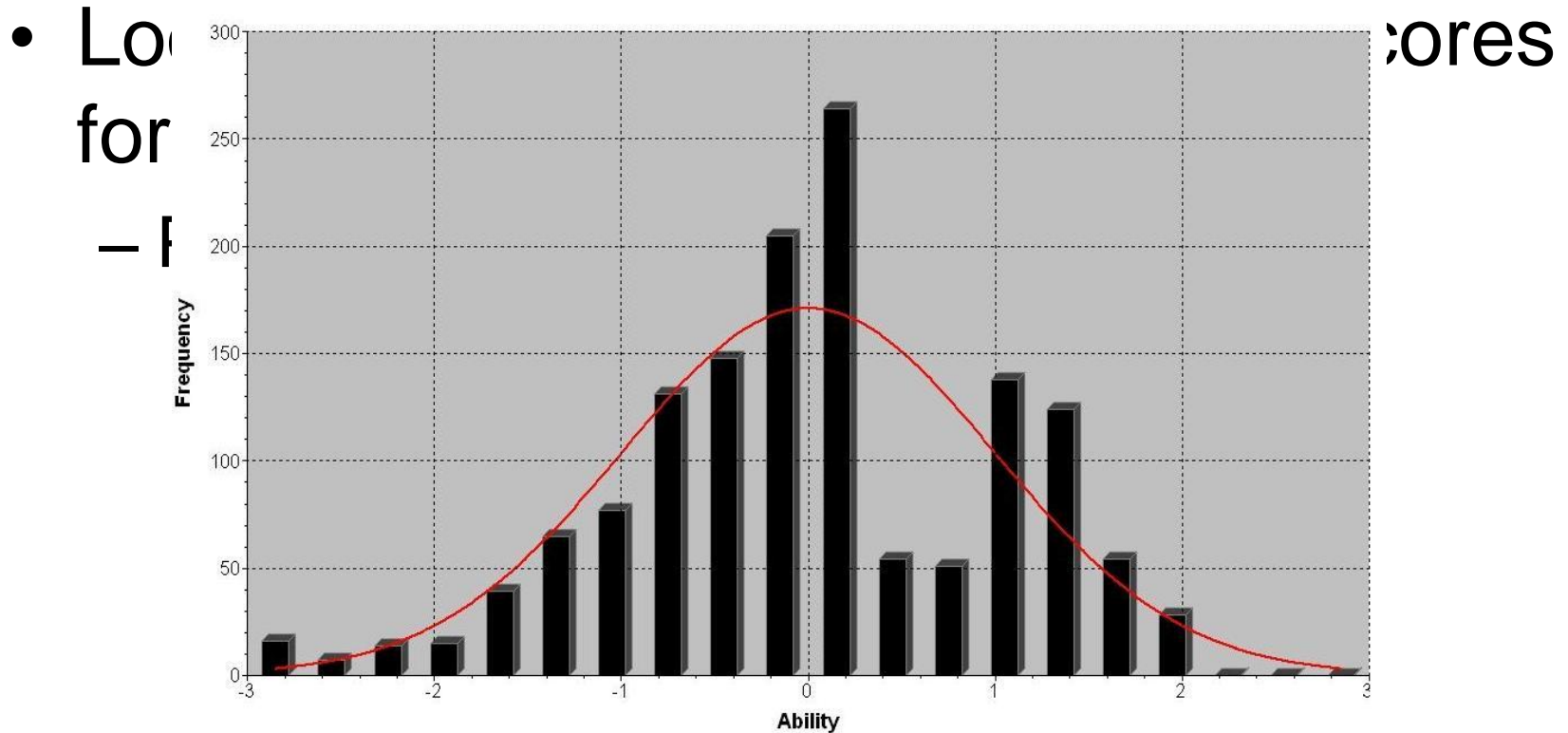
Cognitive Load Theory Implementation in Homework

- Using a two tailed t-test change in test question difficulty for each topic is significantly different at the 99 % confidence interval
- On 7 of 8 topics there was a statistically significant change in retention/learning
- For topics 1, 2, 5, and 7 the increase was $\geq 10\%$
- Only topic 4 (inorganic nomenclature) showed no improvement



Can we show improvement over time?

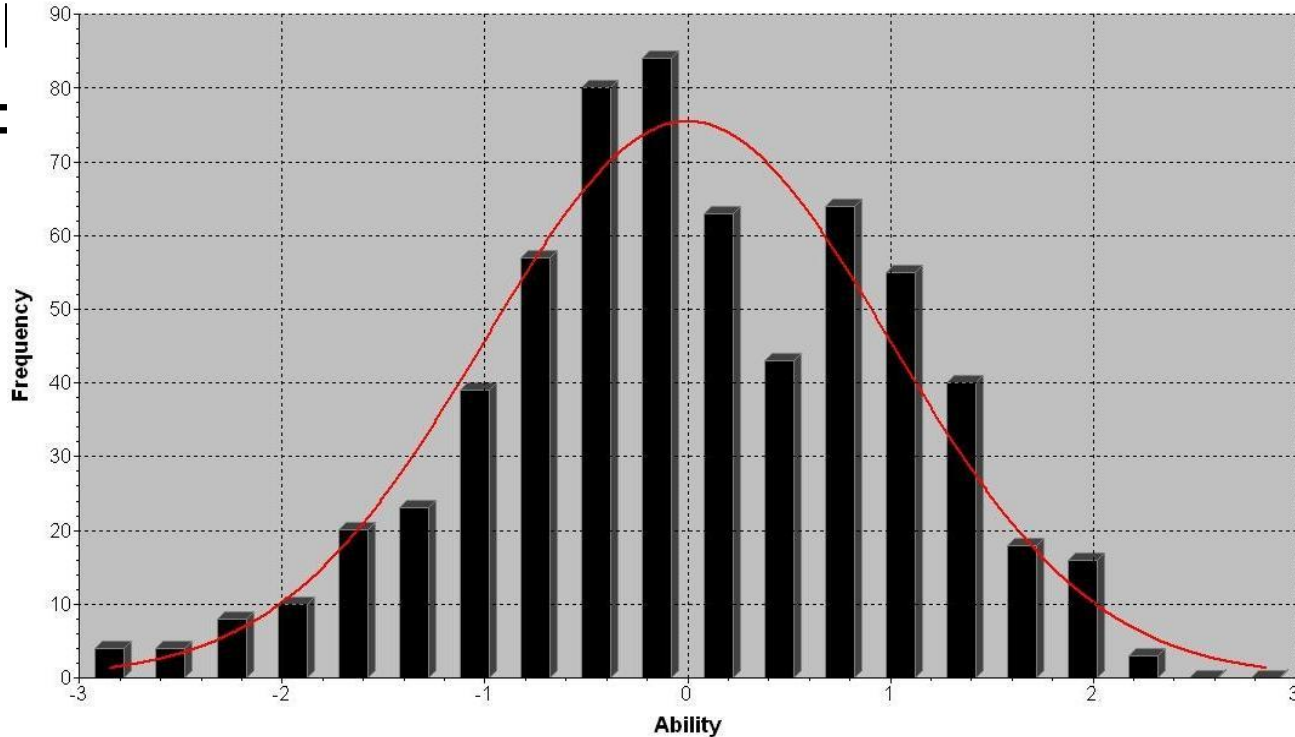
Gaussian Fit to Ability Scores for 1211 Exam 1 2004



Can we show improvement over time?

Gaussian Fit to Ability Scores for 1211 Exam 1 2005

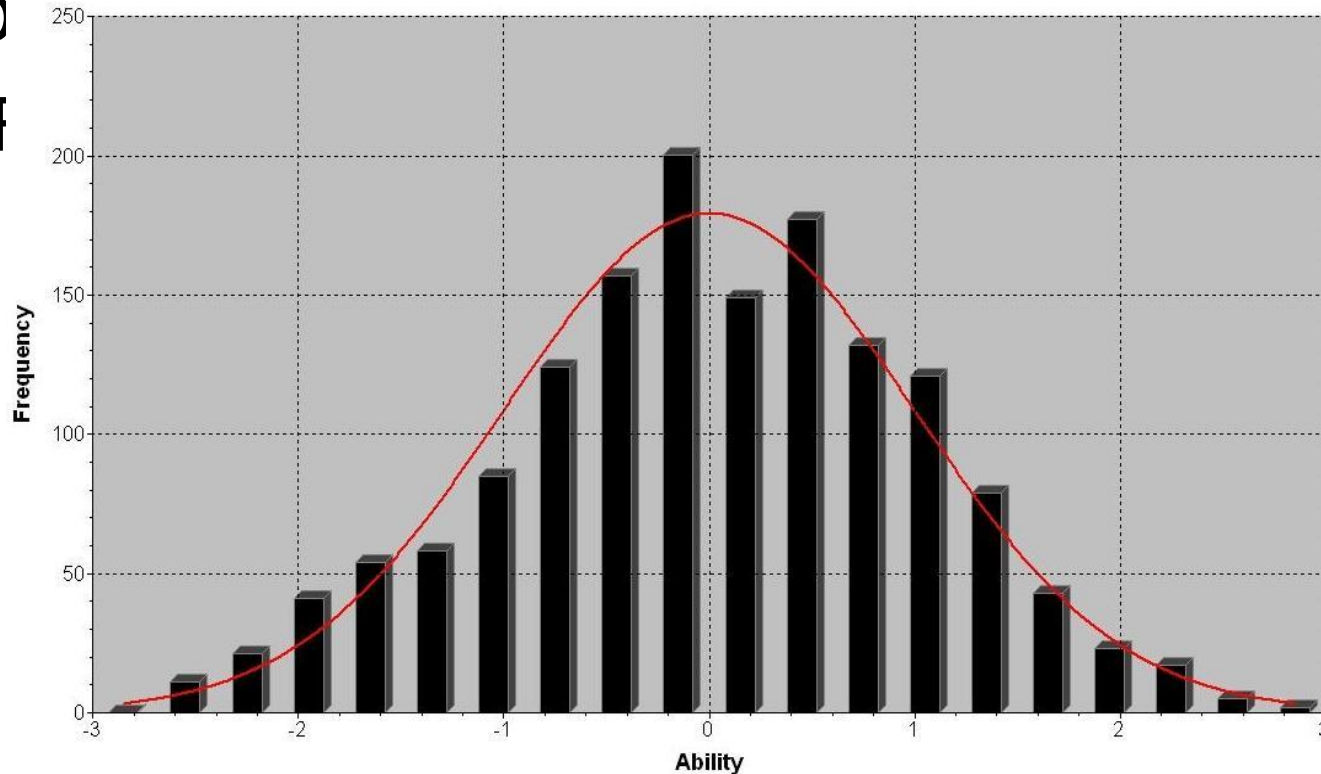
- Col
- F



Can we show improvement over time?

Gaussian Fit to Ability Scores for 1211 Exam 1 2006

- Co
- f



Can we show improvement over time?

Academic Year	A	B	C	D	F
04-05	1.49	0.83	0.17	-0.48	< -0.48
05-06	1.64	1.04	0.45	-0.15	< -0.15
06-07	1.70	1.13	0.55	-0.028	< -0.028
07-08	1.82	1.22	0.63	-0.031	< -0.031
08-09	1.86	1.26	0.66	0.07	< 0.07

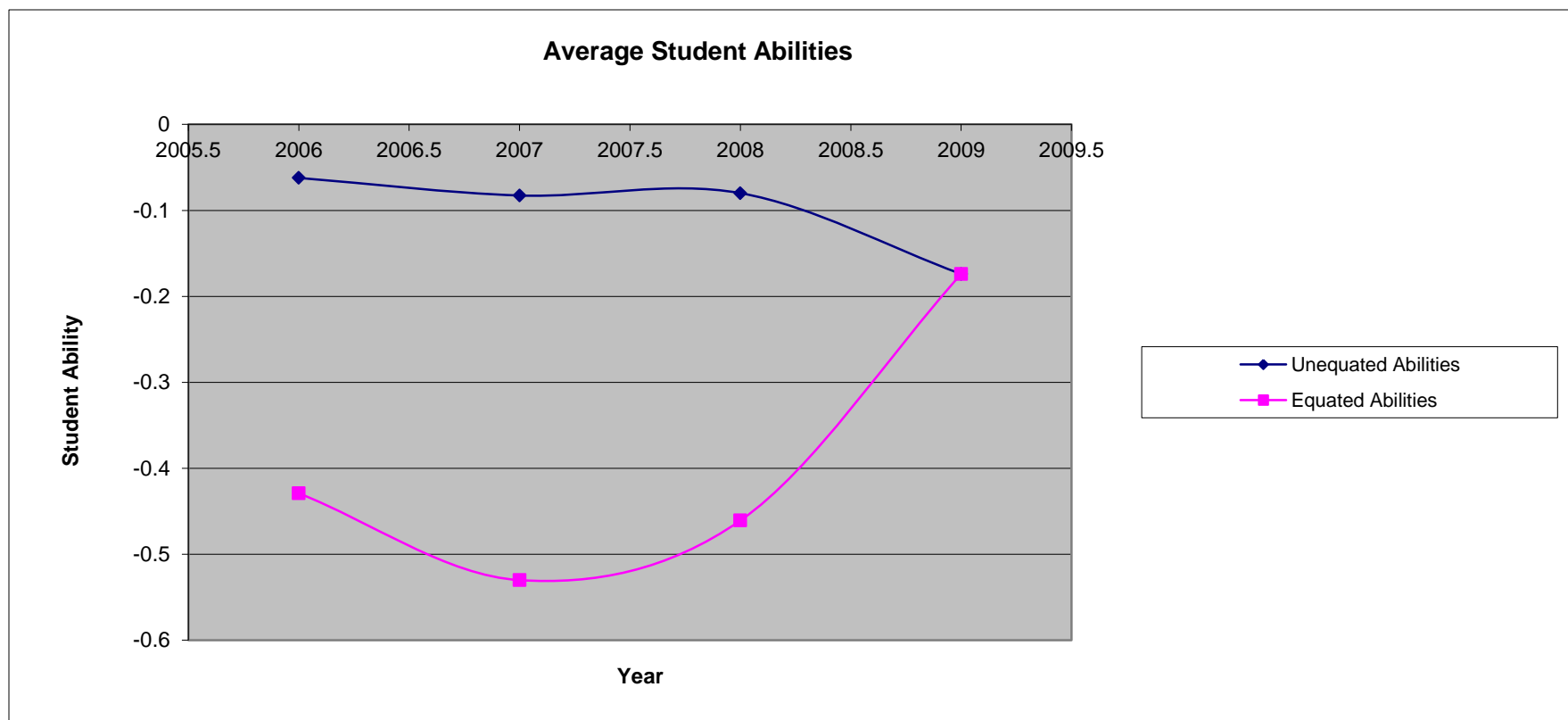


Can we show improvement over time?

- IRT normalizes each year's data to 0
 - Washes out year to year changes
- If at least 15% of the test items are the same from year to year we can use an IRT equating program
 - IRTEQ freeware from UMass-Amherst
- Program normalizes all data relative to one year



Can we show improvement over time?



Stocking, Martha L.; Lord, Frederic M. *J. of Applied Psychological Measurement*, Vol. 7, No. 2, Spring 1983, pg. 201-210



Can we show longitudinal performance improvements?

- External measures of UGA student performance
 - ACS Exam data
- 2005 1st Term Gen Chem Exam data

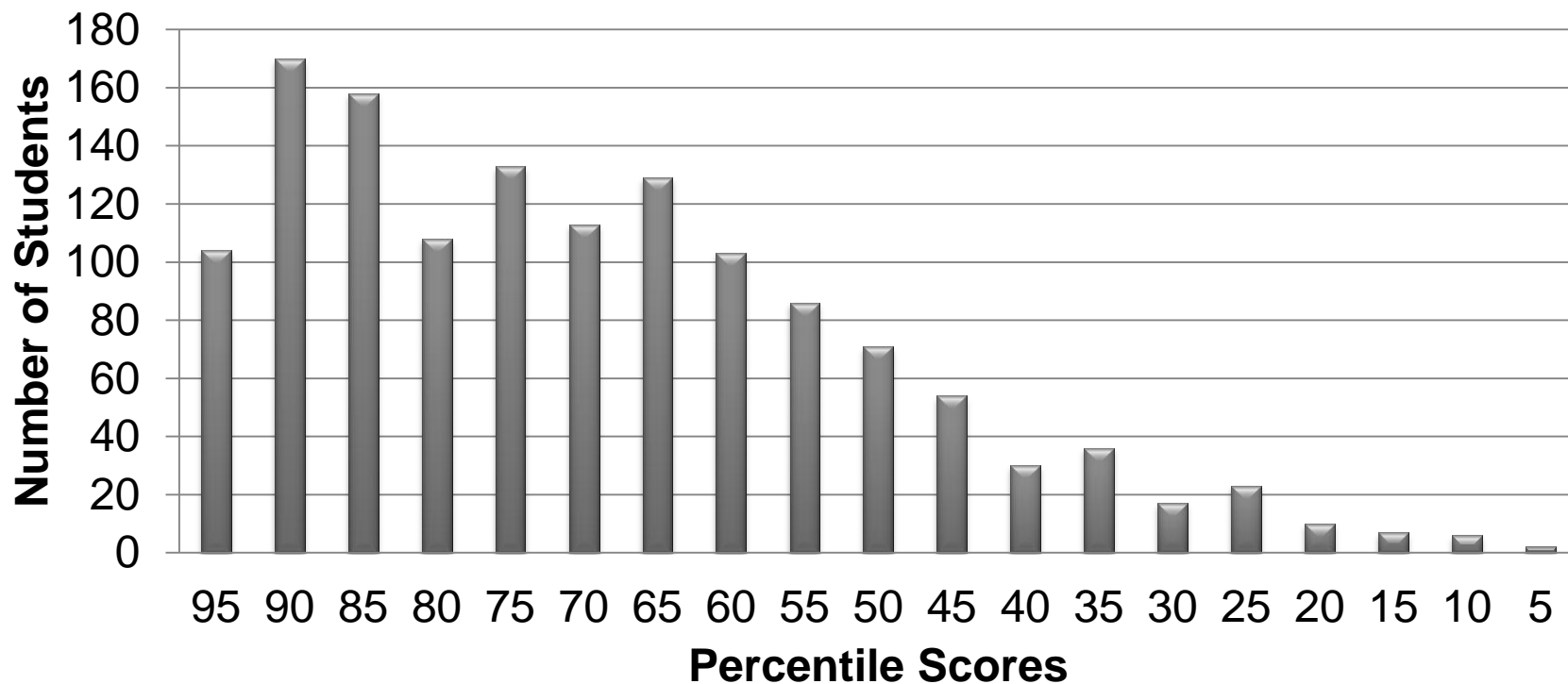


Average = 71.1

Mode = 76.0

1359 Students

Fall 2009 UGA ACS Exam Scores

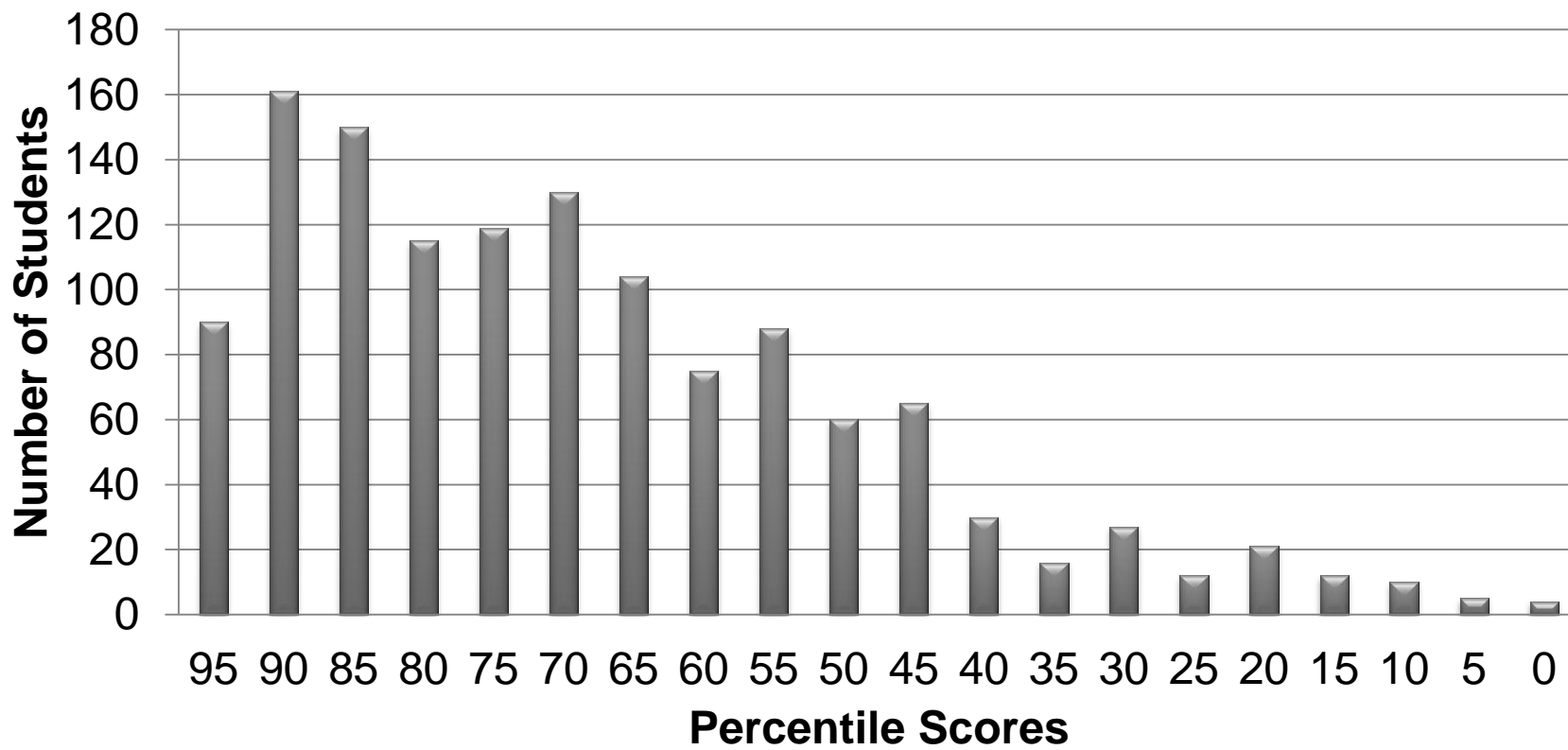


Average = 70.4

Mode = 71

1294 students

Fall 2010 UGA ACS Exam Scores



Conclusion

- Item Response Theory is an effective method to assess likelihood of student success in our course.
- Based upon our IRT analysis we have identified the most problematic topics for our students.
- Proper implementation of cognitive load theory into homework systems can improve student performance.



Acknowledgements

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