Slide 1

Cognitive science, memorization, concepts, and chemistry

Presented At Chem Ed 2015,

By Rick Nelson, Retired Instructor
EANelson@ChemReview.Net

7/31/2015

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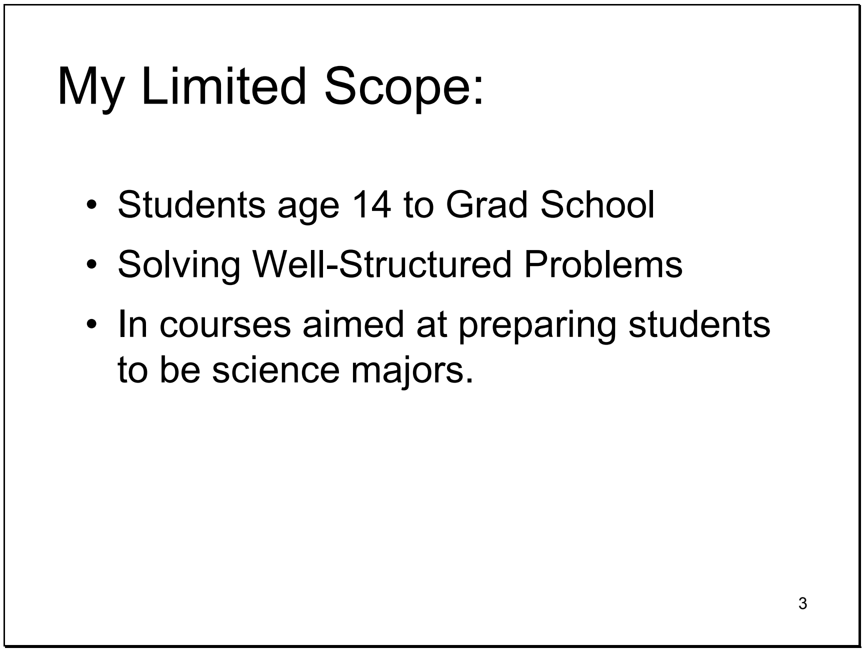
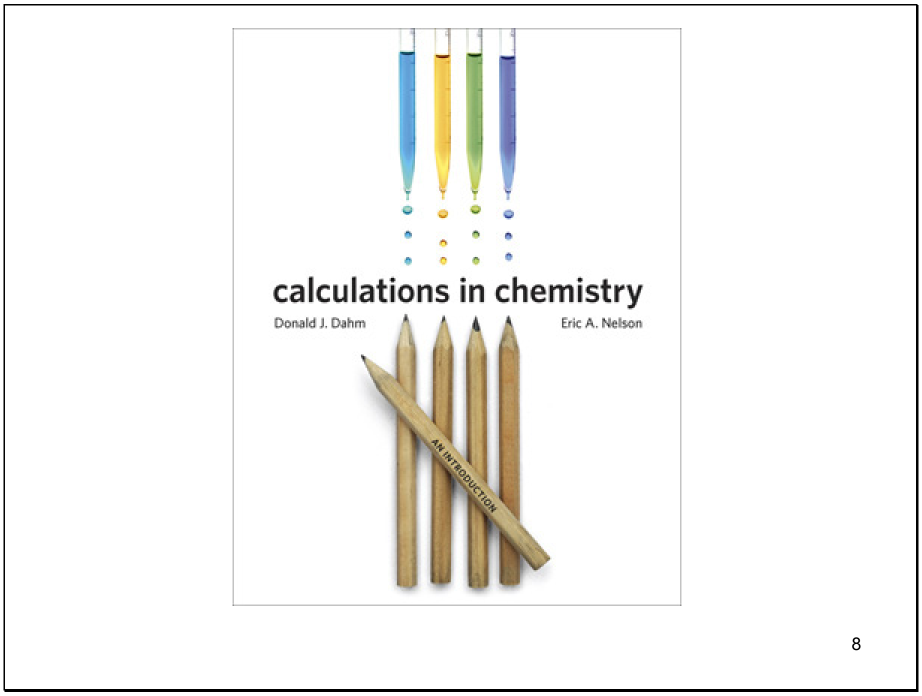
Good afternoon

Slide 3



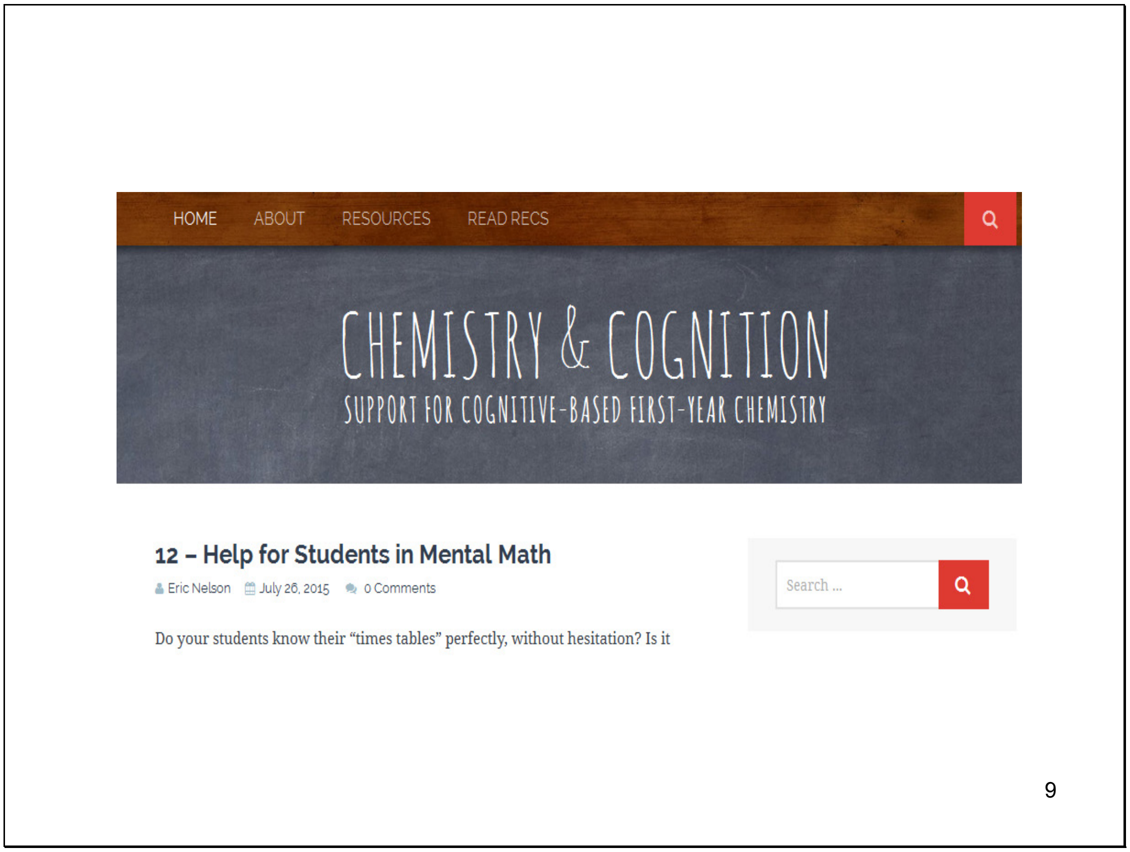
My talk today is limited to addressing students before grad school, solving problems with clear right answers that prepare them to be science majors.

Slide 8



My name is rick nelson. I am co-author with Dr. Don Dahm of Rowan University of this textbook for preparatory chemistry published by W. W. Norton.

Slide 9



I write for the "Chemistry and Cognition" blog,

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JOURNAL OF CHEMICAL EDUCATION

Communication

pubs.acs.org/jchemeduc

ConfChem Conference on Flipped Classroom: Time-Saving Resources Aligned with Cognitive Science To Help Instructors

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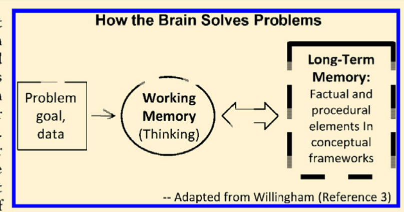
S *Supporting Information*

ABSTRACT: Studies in cognitive science have verified that working memory (where the brain solves problems) can manipulate nearly all elements of knowledge that can be recalled automatically from long-term memory, but only a few elements that have not previously been well memorized. Research in reading comprehension has found that "lecture notes with clicker questions" can move a portion of lecture content to homework. By applying these findings to the design of homework-tutorials for students, under the right conditions, we found that time for active learning during lecture increased and student achievement measurably improved. Factors that have affected the outcome of our experiments are discussed. This communication summarizes



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Was co-author with Don and Dr. Judy Hartman on this paper published last week in J Chem Ed,

Slide 11

Found Chem
DOI 10.1007/s10698-015-9226-z

"Do we need to memorize that?" or cognitive science for chemists

JudithAnn R. Hartman[1] · Eric A. Nelson[2]

Abstract In introductory chemistry courses, should students be encouraged to solve problems by reasoning based on conceptual understanding or by applying memorized facts and algorithms? Cognitive scientists have recently studied this issue with the assistance of new technologies. In the current consensus model for cognition, during problem solving

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But today I'd like to talk about this recent paper that I co-authored with Dr. JudithAnn Hartman who teaches chemistry at the Naval Academy. It will supply the detail and references for my slides and narration. I will post a link to the paper at the end of my slides.

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My Goal:

For You to Remember:

- “I need to look at those slides again.”

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What I am going to talk about is *new* science: findings that cognitive experts agree in 2015 are true, but 10 years ago, not all were convinced were true. Part of what we have learned is that the brain severely limits retention of new knowledge which does not fit into existing conceptual frameworks, so that most of what we talk about today will only “stick” if you review it later. Therefore, I will try to get you curious, and at the end I will give you a web address where you can review any slides of interest at a more reasonable pace whenever you like.

Slide 13

In First-Year Chemistry, **who** is asking for our help?

Slide 14

In General/AP Chem

Are students hoping to major in:

- Chemistry, Physics
- Biology, Biochem, BioTech
- Engineering, Geology
- Pre-Med, Vet, Dental, Optical, Pharmacy
- Medical Technology

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Our mission in HS, AP, and general chemistry is to help students prepare, not for chemistry, but for science.
NSF data tell us that in general/AP chem classes, there will be about 15 future science and engineering majors who graduate for every one chem major graduate. But chemistry plays a central role in all of these fields. When we help students go on to any of these careers, it’s great for them, for us, and for America.

Slide 15

How Are We Doing?

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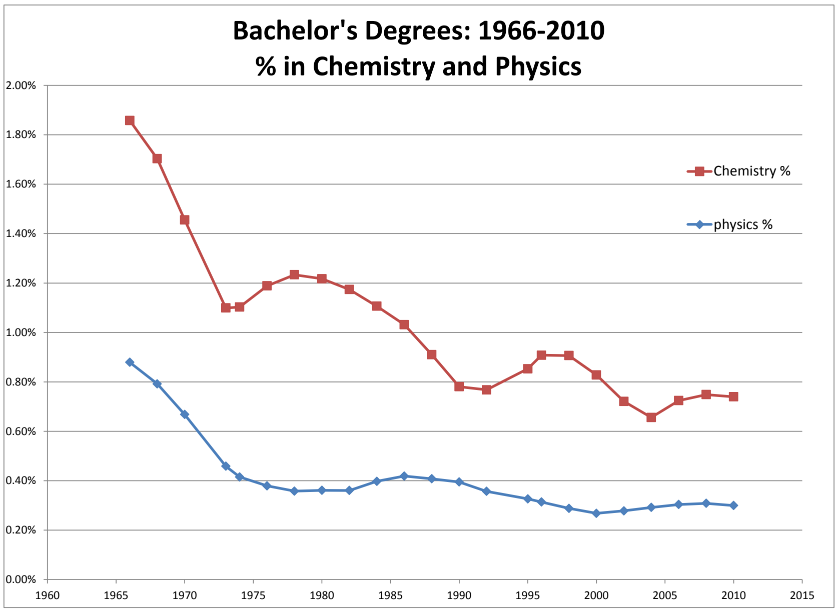
Slide 16



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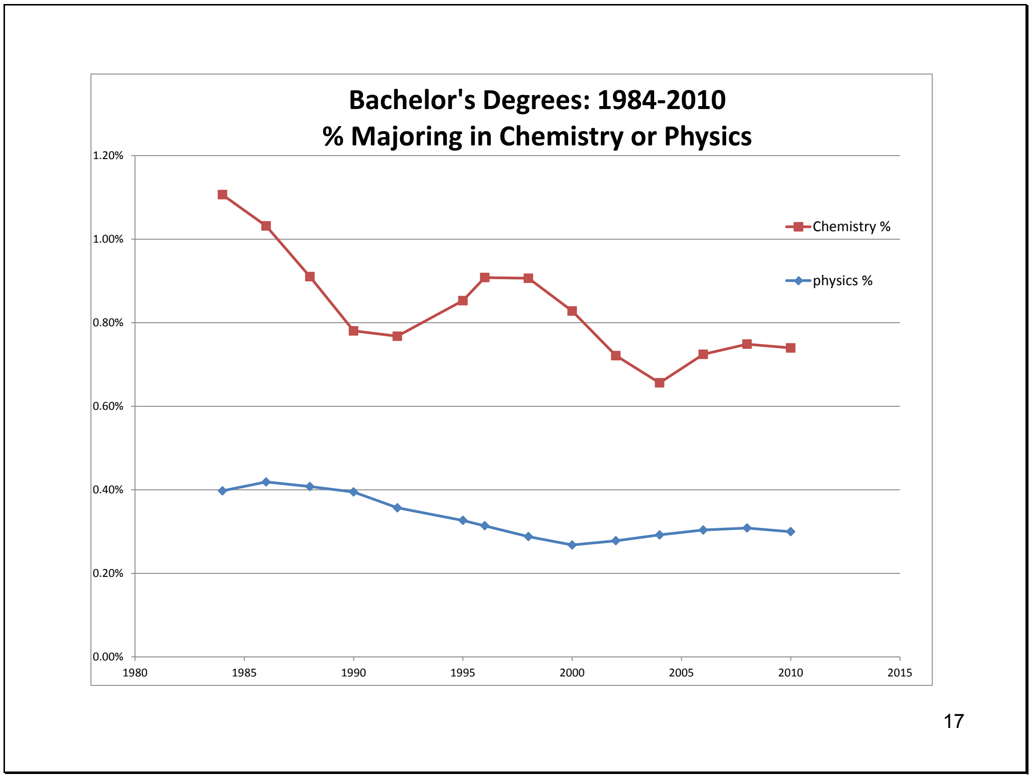
Our work as instructors to help students become science majors has become increasingly difficult.
NSF data tell us that the intent of students entering colleges to major in chemistry, physics, and engineering is as high as it ever been, but since 1966, the percentage of students graduating in chemistry is down about 60%.
The decline in physics is about the same.

Slide 17



In the past ~30 years, the percentage of college students graduating as chem majors is down over 30%.
Might this be because students are instead majoring in Engineering (a mix of chem and physics) where there has been high demand?

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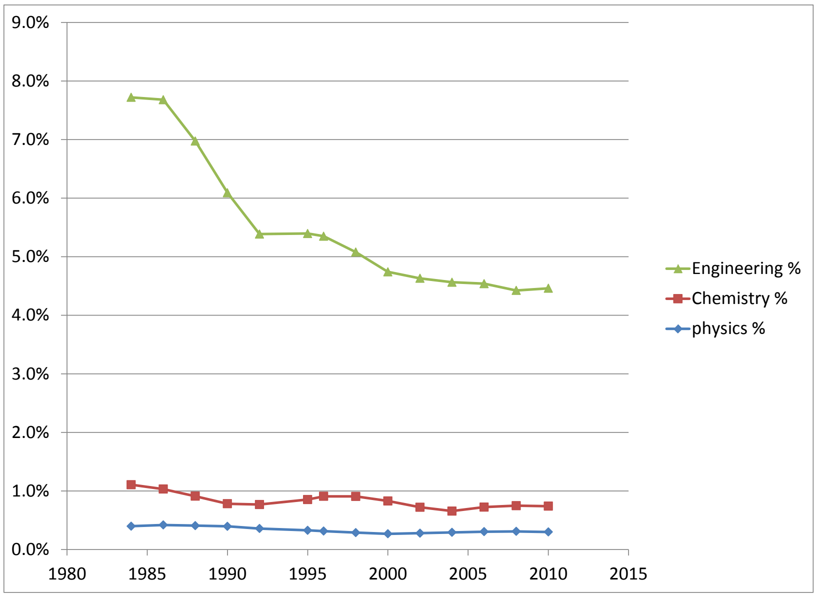
% majoring in Engineering, Chem, Physics 1984-2010



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No. General chem classes prepare 6 times more future engineers than chem majors, but since 1984, the percentage of students graduating in engineering has gone down 40%.

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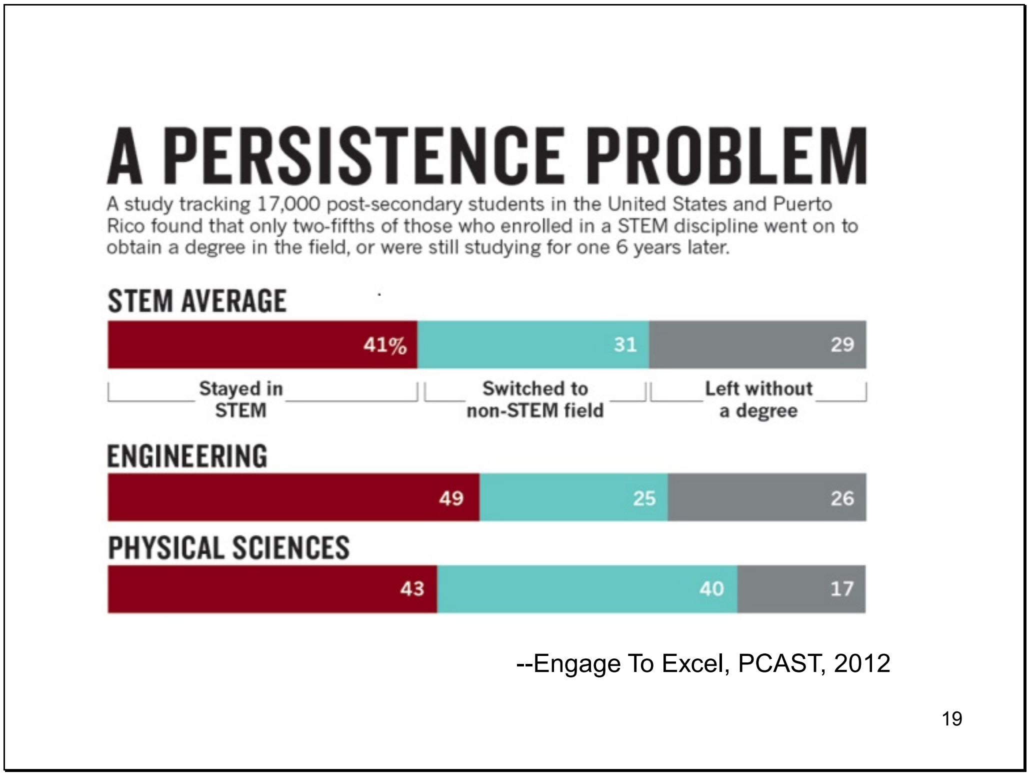

According to the President's Council of Advisors in Science and Technology, among students who initially state their intent to be chemistry and physics majors, dropout rates are close to 60%. For students hoping for careers in the sciences, for instructors, and for America, these are devastating results.

Slide 20

The VERY Good News

- The Problem has NOT been Chem Instruction
- Science has found what went wrong
- Science has found how we can FIX the problem.

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Here's the good news.

Slide 21

$$\mathcal{E} = \mathcal{E}^\circ_{\text{cell}} - \frac{0.0591}{n}\log(Q)$$

$$= 1.76 - \frac{0.0591}{2}\log\left(\frac{[Zn^{2+}][VO^{2+}]^2}{[VO_2{}^+]^2[H^+]^4}\right)$$

$$= 1.76 - \frac{0.0591}{2}\log\left(\frac{(1.0 \times 10^{-1})(1.0 \times 10^{-2})^2}{(2.0)^2(0.50)^4}\right)$$

$$= 1.76 - \frac{0.0591}{2}\log(4 \times 10^{-5}) = 1.76 + 0.13 = 1.89\ \text{V}$$

-- Zumdahl, 5th edition

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The evidence is that what went wrong is student background in math computation. Other science majors require first-year chemistry because when we teach chem, we also teach how to solve calculations that are required in all of the sciences --- that look like this with logs, exponents, and fractions,

Slide 22

Thus

$$u_{\text{rms}} = \sqrt{\frac{3\left(8.3145 \frac{\text{J}}{\cancel{\text{K}} \cdot \cancel{\text{mol}}}\right)(298\ \cancel{\text{K}})}{4.00 \times 10^{-3} \frac{\text{kg}}{\cancel{\text{mol}}}}} = \sqrt{1.86 \times 10^{6} \frac{\text{J}}{\text{kg}}}$$

Since the units of J are kg · m^2/s^2, this expression becomes

$$\sqrt{1.86 \times 10^{6} \frac{\cancel{\text{kg}} \cdot \text{m}^2}{\cancel{\text{kg}} \cdot \text{s}^2}} = 1.36 \times 10^{3}\ \text{m/s}$$

-- Zumdahl, 5th Ed. p. 218

Square roots, exponents, and fractions

Slide 23

$$\mathcal{M} = \frac{dRT}{P}$$

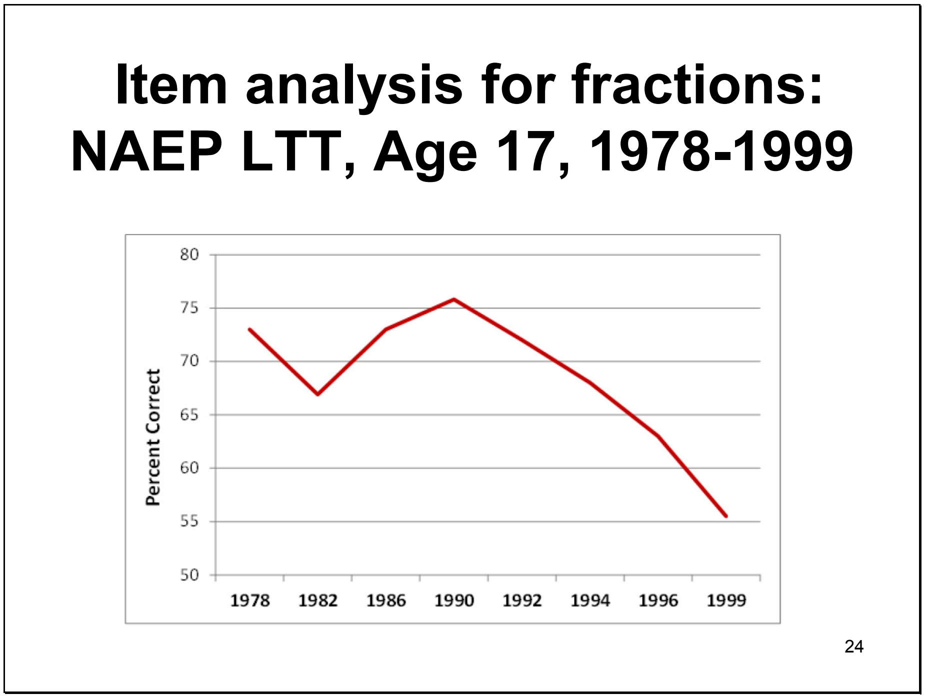
$$= \frac{(3.09\ \text{g/L})(0.0821\ \text{L-atm/mol-K})(304\ \text{K})}{(735/760)\ \text{atm}}$$

$$= 79.7\ \text{g/mol}$$

-- Brown, Lemay, 8th Ed. p. 368

In chemistry we teach equations, and how to correctly identify the data to put into an equation, as in the middle step above. But that middle step has 4 / marks: 4 fractions. Given the pace of general chemistry, textbooks often assume that students can go from the middle to the last step without help, as you see above - that in prior math, they have learned how to handle fractions. Is that assumption correct?

Slide 24



On our national test of math skills, the NAEP , in fractions, our 17-year olds went from **24%** wrong in 1990 to **44%** wrong in 1999.

Slide 25

$$\mathscr{E} = \mathscr{E}^\circ_{\text{cell}} - \frac{0.0591}{n}\log(Q)$$

$$= 1.76 - \frac{0.0591}{2}\log\left(\frac{[Zn^{2+}][VO^{2+}]^2}{[VO_2{}^+]^2[H^+]^4}\right)$$

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-- Zumdahl, 5th edition

This is math computation.

Slide 26

Thus

$$u_{\text{rms}} = \sqrt{\frac{3\left(8.3145 \frac{\text{J}}{\cancel{\text{K}} \cdot \cancel{\text{mol}}}\right)(298\ \cancel{\text{K}})}{4.00 \times 10^{-3}\ \frac{\text{kg}}{\cancel{\text{mol}}}}} = \sqrt{1.86 \times 10^{6}\ \frac{\text{J}}{\text{kg}}}$$

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-- Zumdahl, 5th Ed. p. 218

Computation.

Slide 27

$$\mathcal{M} = \frac{dRT}{P}$$

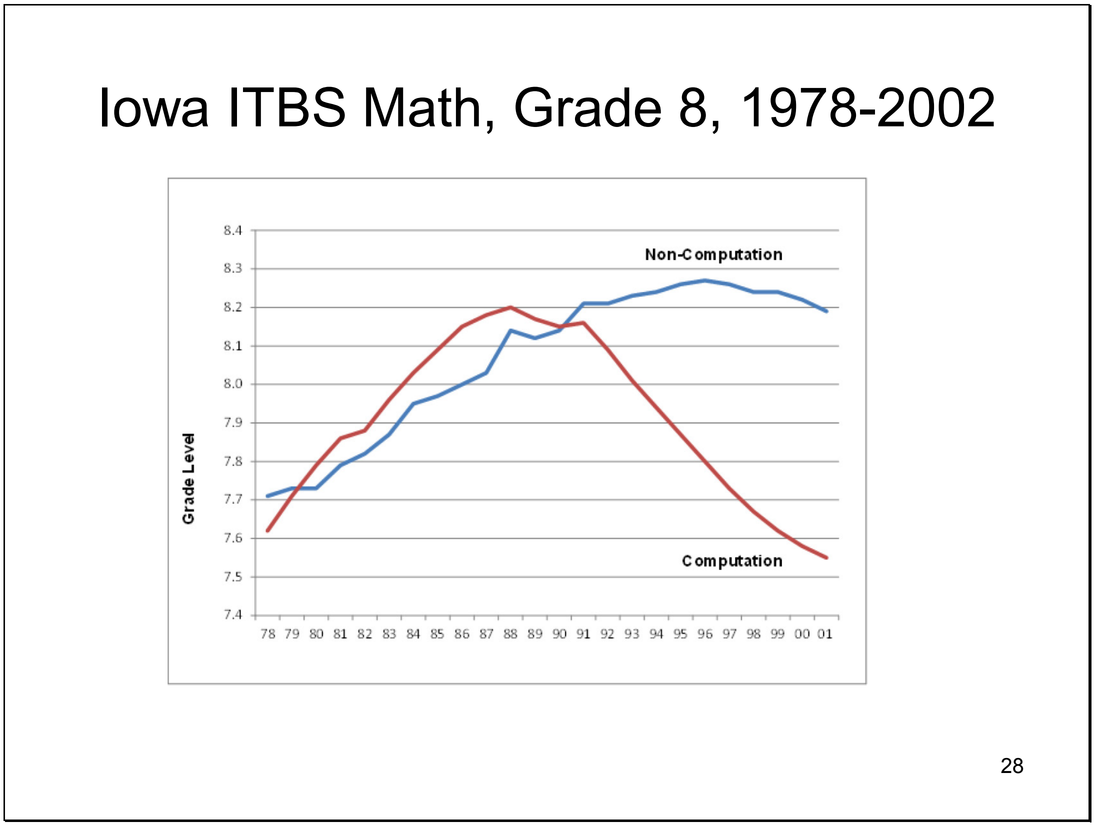
$$= \frac{(3.09\ \text{g/L})(0.0821\ \text{L-atm/mol-K})(304\ \text{K})}{(735/760)\ \text{atm}}$$

$$= 79.7\ \text{g/mol}$$

-- Brown, Lemay, 8th Ed. p. 368

Computation. But since 1990, student skills in computation have declined substantially.

Slide 28



Compare 1990 Iowa to 2002 in math computation.

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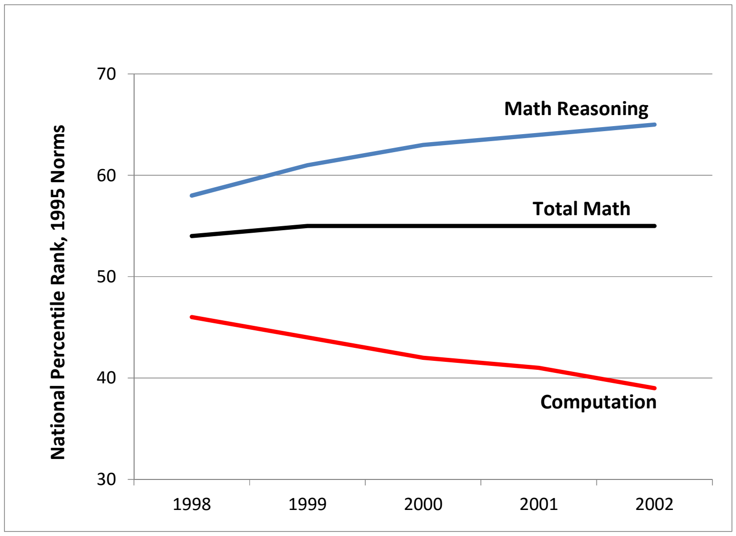
Virginia, Grade 9, 1998-2002

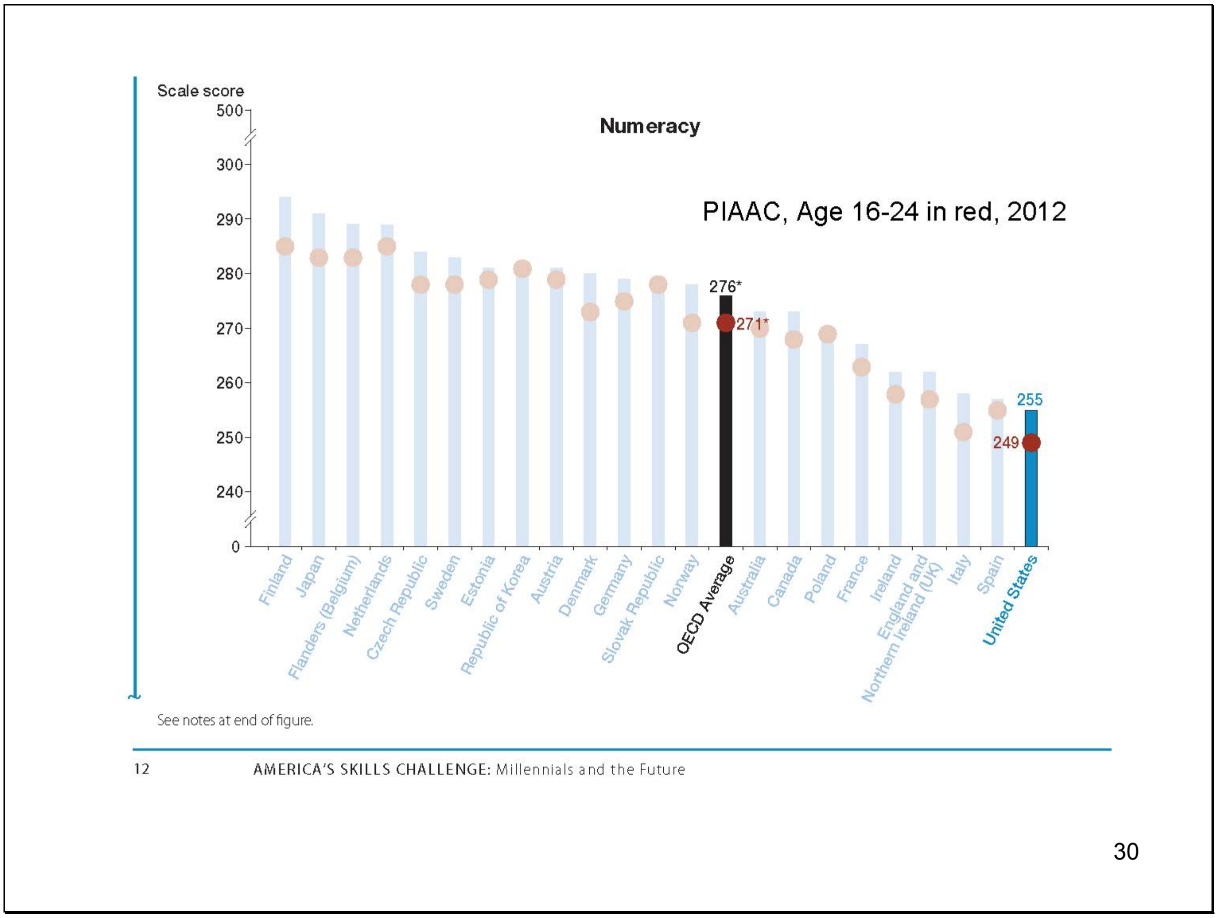


29

In Virginia, by 2002, the state computation average fell to the abysmal 39th percentile (compared to a 1995 national average 50th percentile).

(Since 2002, most states have not reported computation data; see www.ChemReview.Net/BCCE2012Math.pdf)

Slide 30



In 2012, the OECD gave a test in numeracy (fundamental arithmetic skills) to adults in 22 nations.
The red dots are the 16-24 year olds in each nation. Where are your students? Where? Dead last. Is it any wonder that our students have trouble in ….

Slide 31

Thus

$$u_{\text{rms}} = \sqrt{\frac{3\left(8.3145 \frac{\text{J}}{\cancel{\text{K}} \cdot \cancel{\text{mol}}}\right)(298\ \cancel{\text{K}})}{4.00 \times 10^{-3}\ \frac{\text{kg}}{\cancel{\text{mol}}}}} = \sqrt{1.86 \times 10^{6}\ \frac{\text{J}}{\text{kg}}}$$

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-- Zumdahl, 5th Ed. p. 218

Chemistry?

Slide 32

- WHY did US computation/numeracy skills collapse?

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As instructors, our goal is to improve student success rates in science majors.
To do so, we need to know: What went wrong in computation?
The evidence is that problems grew as calculators were being used at earlier and earlier grades in schools, but that problems became especially acute after 1990.

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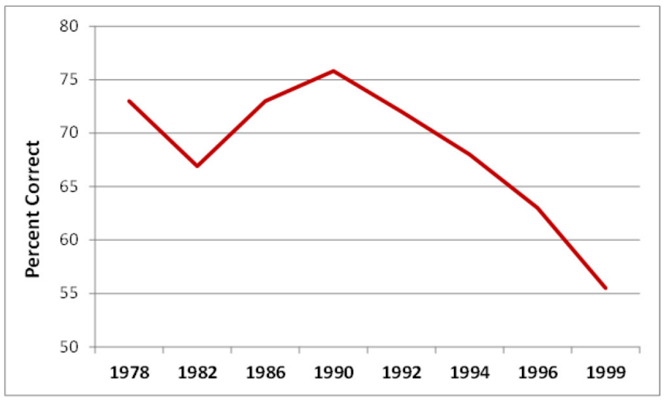
Item analysis for fractions: NAEP LTT, Age 17, 1978-1999



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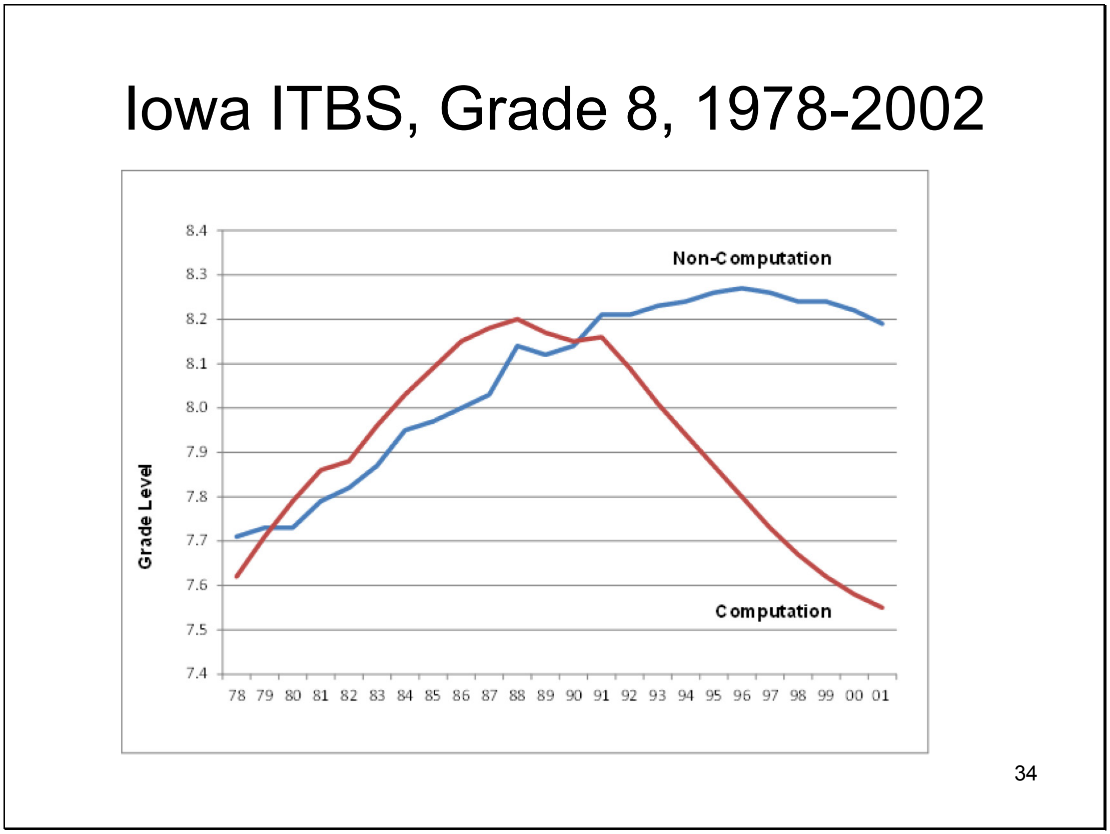
Note 1990 to 2002?

Slide 34



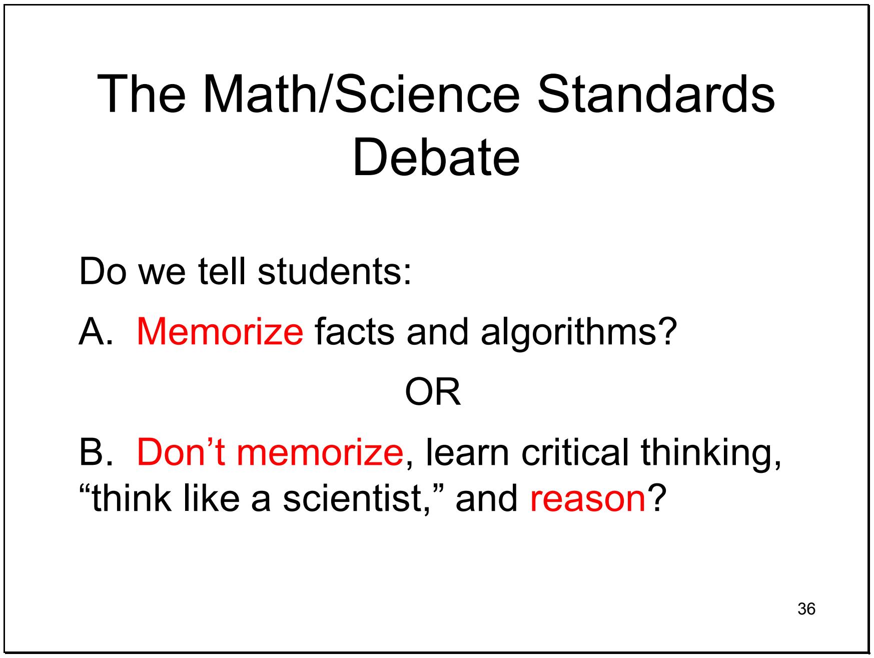
See 1990? What happened in 1990?

Slide 35

35

After the 1989 "Charlottesville Education Summit," the US began a move from local K-12 education standards to "state standards." By 1998, nearly every state had "state math standards" and tests on those standards.

Slide 36



At that time, this question was being debated among curriculum policy-makers.
Let me ask: In chemistry education journal articles and at conferences, which position do most speakers advocate:
Approach A – or B? How many think speakers favor A ? Favor B ?

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The Standards Debate

Do we tell students:

A. Memorize facts and algorithms?

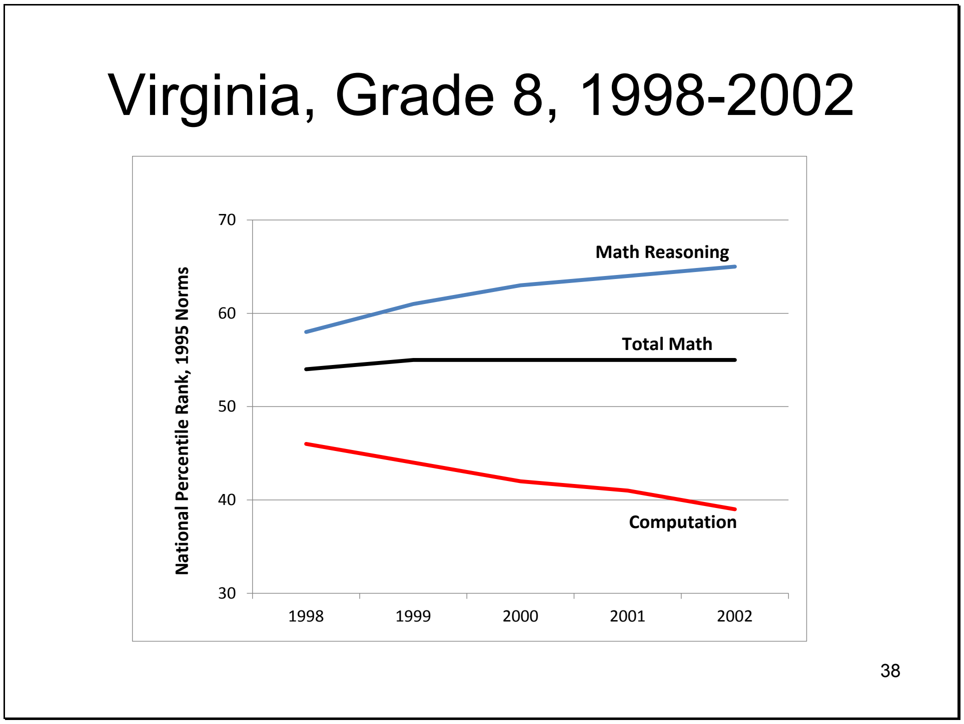
OR

B. Don't memorize, learn critical thinking, "think like a scientist," and reason?

37

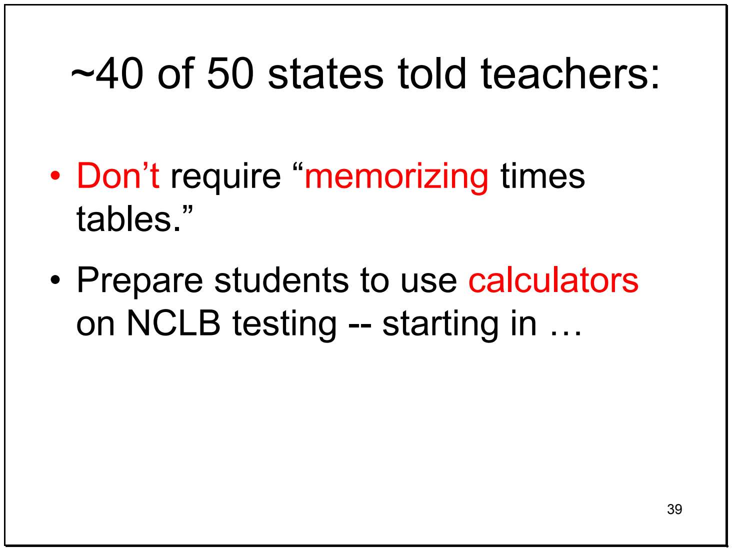
Between 1990 and 2000, about 40 of the 50 US states adopted standards and textbooks that guessed **B:** that memorization should be discouraged and reasoning should be emphasized.
This was a guess because in 1990, experts in how the brain works were not in consensus on how the brain solves problems.

Slide 38



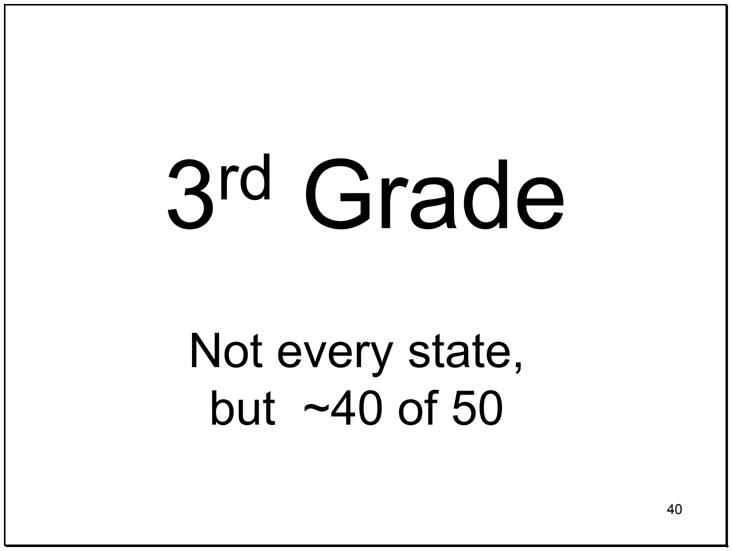
You can see this impact. Virginia math standards told teachers to emphasize math reasoning. They did, and students did get better at reasoning.

Slide 39



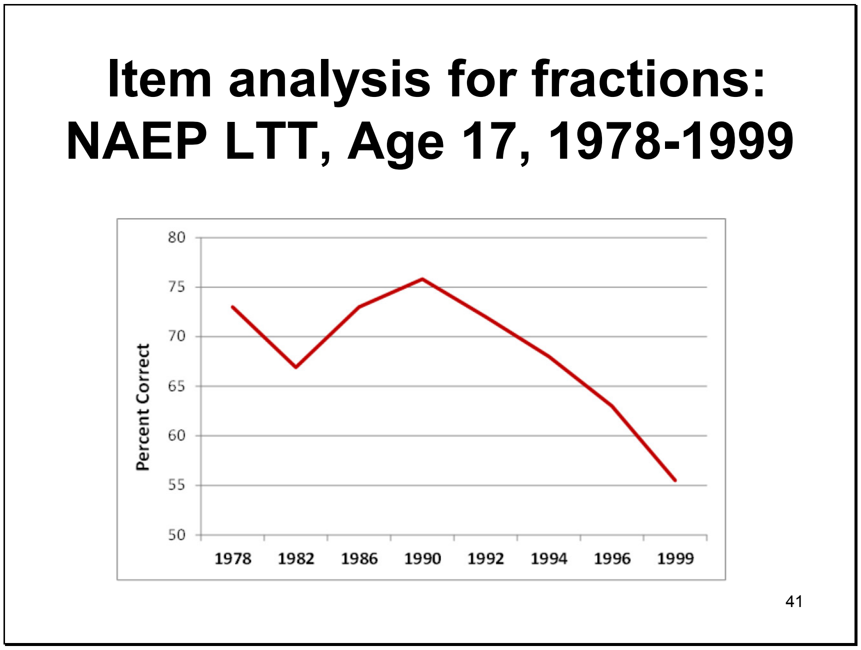
About 40 of 50 states told teachers this. Take a look. Which grade?

Slide 40



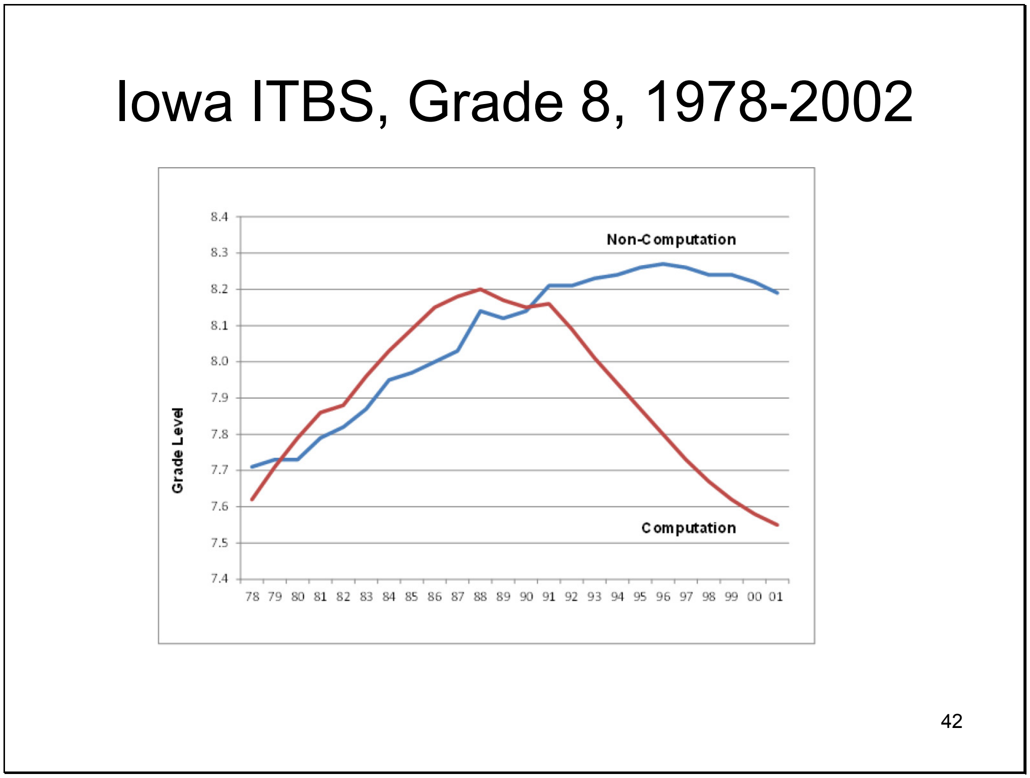
And what happened?

Slide 41



Nationally?

Slide 42



In Iowa

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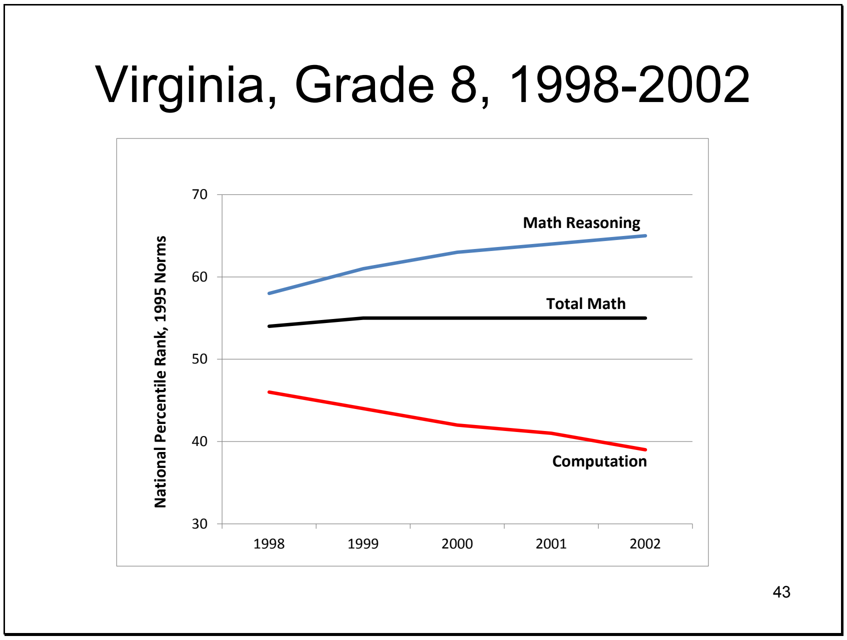
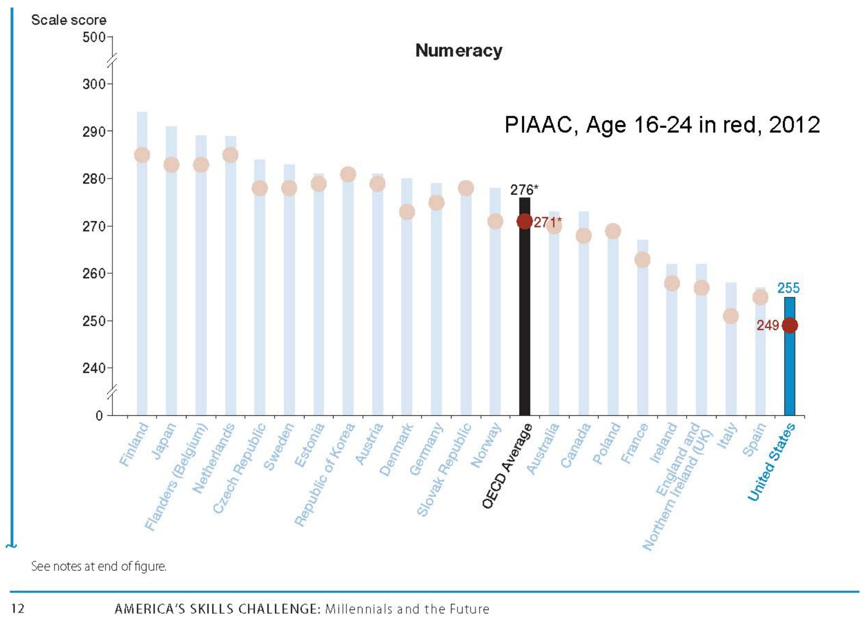


With standards told students “Don’t memorize, reason,” computation skills fell apart. Virginia students learned to reason, and used calculators on state tests, but Computation, a key preparation for science majors, collapsed.

Slide 44



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On the 2012 PIACC/OECD test, where calculators were allowed, for America: dead last.

The “pro-reasoning, anti-memorization” state standards and the drop in computation skills occurred at the same time. That’s a correlation. But were the standards a major factor causing the drop? Let’s look at the evidence.

Slide 45

Studying the Brain

1990 – Few tools to study living brain

By 2005 –

- **fMRI** – functional magnetic resonance imaging
- **MEG** – Magnetoencephalography
- **PET** – Positron Emission Tomography
- Eye Movement Tracking

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Since 1990, thanks to technology and increased computing power

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Increasingly, we can watch the brain think. With the help of that technology, for about the past 10 years, nearly all cognitive scientists have been in agreement on the major elements of a model for how the human brain solves well-structured problems.

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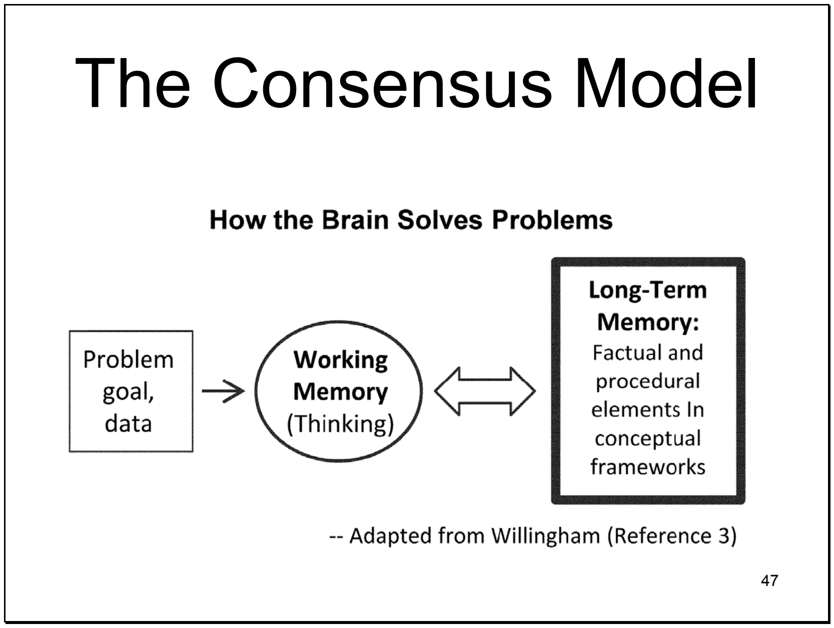

In that consensus model, the brain where you solve problems has two parts: Working memory and Long-Term Memory. What makes the human species unique is the enormous capacity of the Long-Term Memory (LTM) where we store knowledge.

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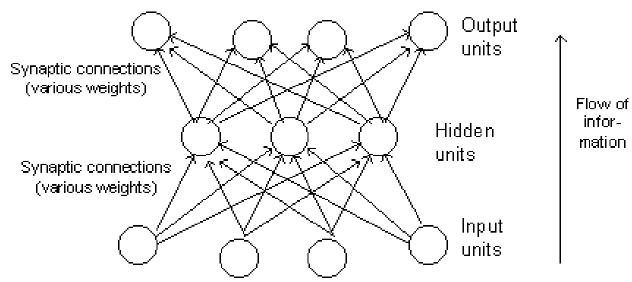
Models for Long-Term Memory



(Based on a figure in Churchland 1993:156)

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LTM has a structure similar to a parallel processing computer.

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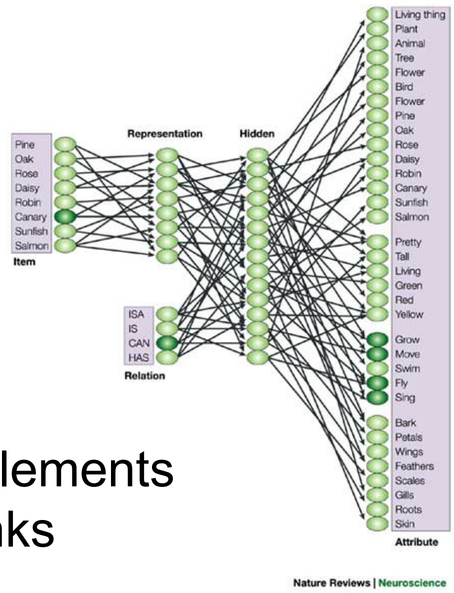

LTM: Elements and Links

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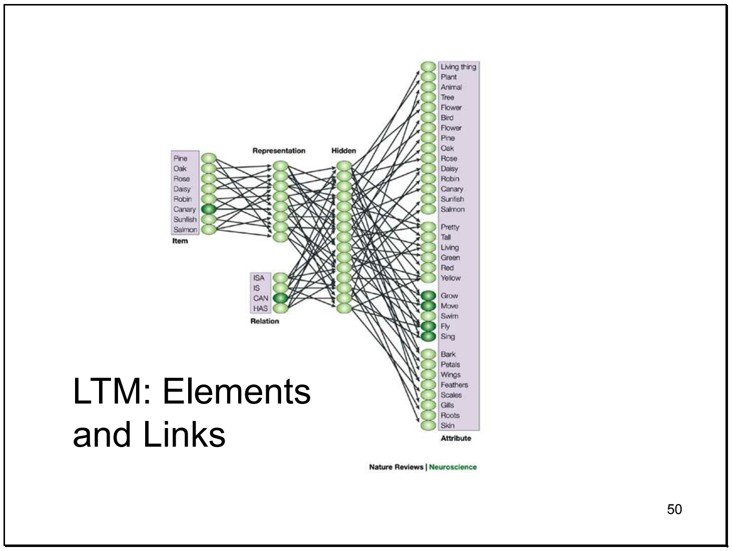
LTM is made up of small *elements* of knowledge *associated* with other elements. Those *linkages* describe its meaning of each element and the rules for its use. Those links *activate* in response to cues.

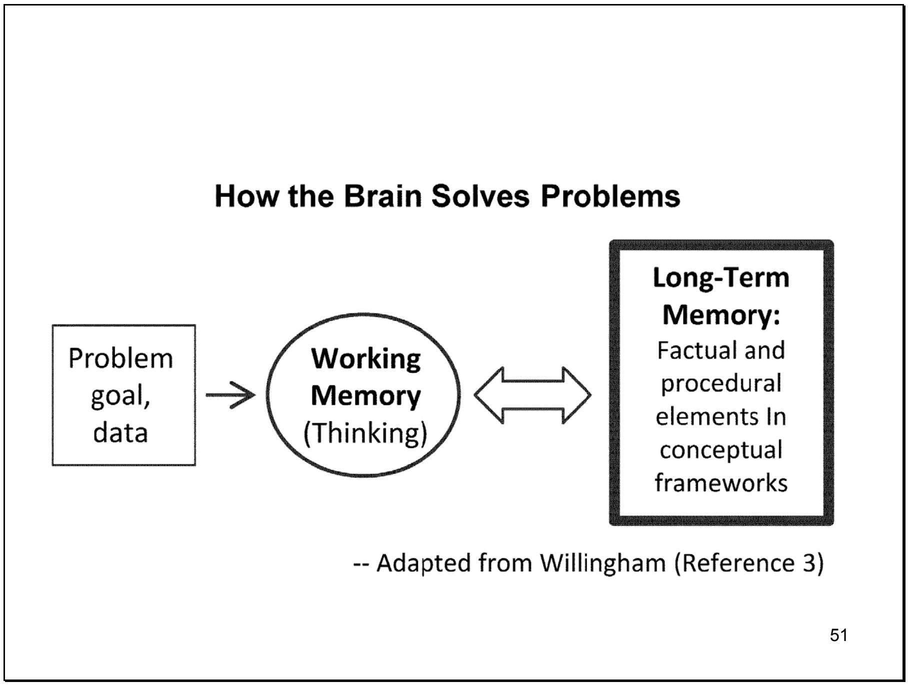
For example, if I make the sound “copper,” what associations come to mind?

Slide 50



All make up the “conceptual framework” for “copper” in your brain.
LTM is enormous: Over a billion small stored elements, including thousands of faces, places, names, dates, tastes, odors and sounds. Plus, most college educated adults can define from memory about 70,000 dictionary words. In speech, we effortlessly both choose correct words and apply complex rules for their use.

Slide 51



The goal of learning is to solve problems. The place the brain solve problems is in working memory (WM) by processing elements that have recently been read or heard – or activated in LTM. Everything activated in your LTM by a cue in a problem (such as "copper") can be retrieved by WM to solve the problems.

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The *Limit* on Reasoning:

During problem solving, **working memory** can hold and process

- ~All elements that can be recalled automatically from LTM.

Plus

- Up to **3-5** elements, each for **up to 30 seconds,** that *cannot* be fluently recalled from LTM.

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But this is the speed limit of your brain. Take a look.
Until 2001, we thought this 3-5 was about 7. Now we know -- it’s about 4.
By 2005, these measurements were well-tested, verified scientific data.

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WM can hold and process

- ~All elements recalled automatically, plus
- Up to **3-5 non-memorized** elements.

Given ^ is true, is this true?

- Working memory is *very* limited when dealing with information that has not previously been memorized.

Vote: Yes? No?

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Let's examine what these measurements mean.
Given this is true, how many vote this is true? Yes? No?

Slide 54

WM can hold and process

- ~All elements recalled automatically, plus
- Up to **3-5 non-memorized** elements for up to 30 seconds.

Given ^ is true, is this true?

- When solving chem problems, speed at recall matters.

Vote: Yes? No?

Is this true?

Slide 55

If your “novel” (new to you) WM is full, will this step during problem solving bump something out?

- Recall of 6 x 7 = from memory: Y or N?
- Adding to WM the calculator answer to 6 x 7 = : Y? N?

55

What was the policy of most states on times tables? As calculator use grew, mental math likely got rusty, but when states required early calculator use, the problem likely got worse.

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WM can hold and process

- ~All elements recalled automatically, plus
- Up to **3-5 non-memorized** elements.

Given ^ is true, is this true?

- The more elements you move into LTM (memorize) and link, the more problems you can solve.

Vote: Yes? No?

56

How many would agree? Disagree?

Slide 57

Avoiding the Bottleneck:

- "[T]here are several ways to improve the functional capacity of working memory. The most central of these is the achievement of *automaticity*, that is, the fast, implicit, and automatic retrieval of a fact or a procedure from long-term memory."

  -- David Geary, Valerie Renya, Robert Siegler, Susan Embertson, Wade Boykin. *Report of the National Mathematics Advisory Panel* (NMAP), Chapter 4, 2008.

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This is what the cognitive experts say. Take a look. What is central to getting around the bottleneck in WM? And what is automaticity?
Those 5 leading scientists who study how the brain solves problems (and many other cognitive scientists) have written that they agree on this. Just as important, for the past 5 years, no cognitive experts have disagreed with what this says. When that happens, we have a scientific consensus.

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They Add:

- "[t]o obtain the maximal benefits of automaticity…, facts and fundamental algorithms should be thoroughly mastered, and indeed, over-learned, rather than merely learned to a moderate degree of proficiency.

-- (Geary et al., NMAP 2008)

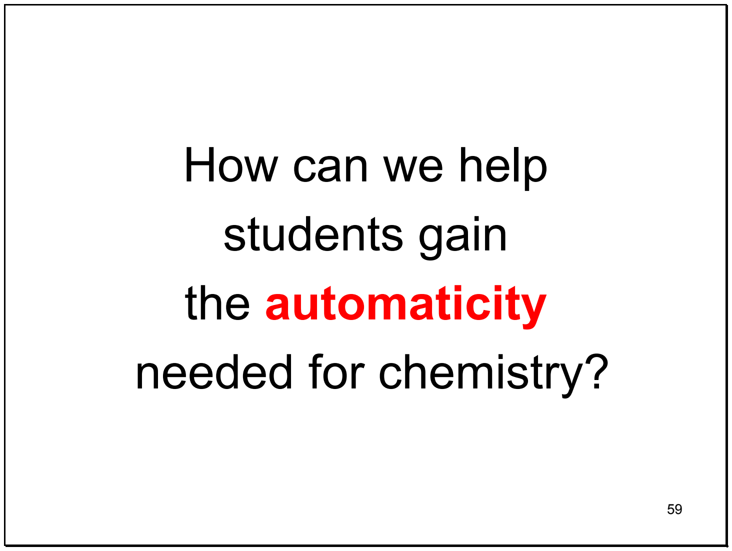
"Overlearned" = ?

58

They go on to say this. Who knows what "overlearned" means?
"Over-learned" means facts and algorithms are memorized until they can be recalled fast, perfectly, *repeatedly*. Even for instructors who have assumed a need for memorization in chemistry, the extent to which science says students need to memorize may be surprising.

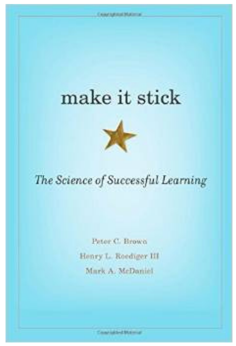
Why is overlearning needed? LTM resists new information that does not "fit" in an existing conceptual framework. After ~age 12, it takes *repeated* and *varied* efforts to persuade LTM to hold on to new knowledge in unfamiliar fields.

Slide 59



Knowing automaticity plays a central role in problem solving, for instructors this becomes a key question.

Slide 60



2014:

Make It Stick

By (novelist Brown) and cognitive scientists Roediger and McDaniel

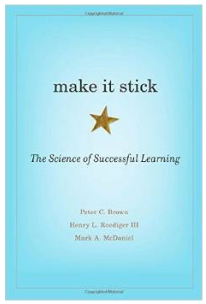
Harvard Univ. Press

60

This new book – by these scientific authors – by this semi-reputable publisher does a great job of explaining what *students* can do to …

Slide 61

To achieve automaticity:



FIRST, *practice retrieval* :

- Overlearn elements
- Distribute practice (the spacing effect)
- Self-test (clicker questions, flashcards, mnemonics)
- Quiz *(closed* notes) often
- Fade guidance (scaffold)

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It says,

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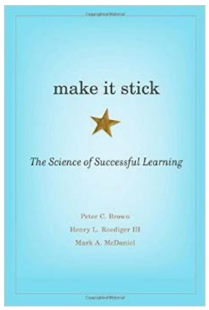
Then



Construct varied linkages that promote cued recall – using *active* learning:

- Demonstrations
- Guided inquiry
- Challenging problems
- Interleaved practice
- Reflection, elaboration

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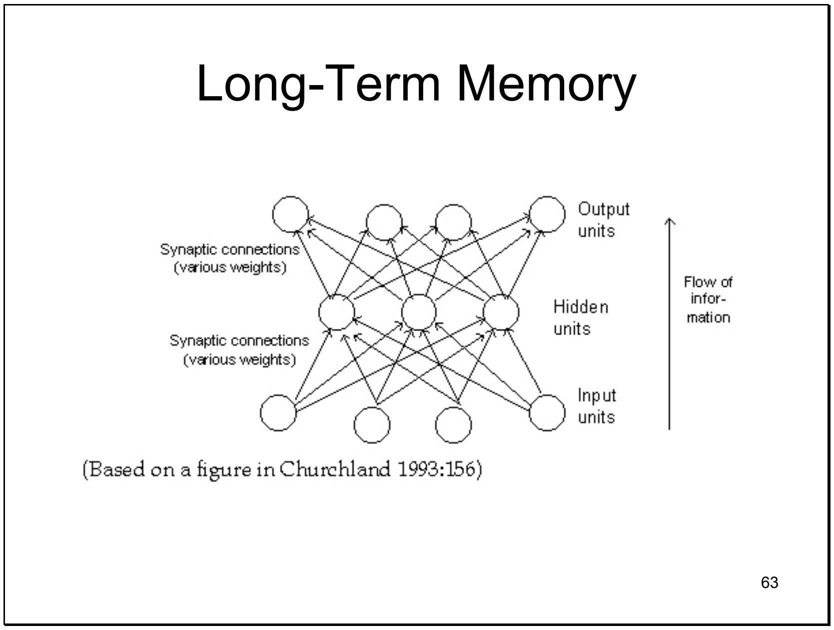
Instructors can help in building conceptual frameworks by engaging students in active learning.

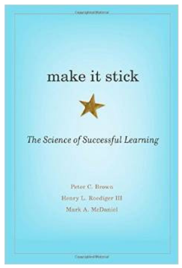
Slide 63



Before you can build the linkages, an element must be moved into LTM ("memorized"). The brain accepts new information more easily if the associations are present, but that makes initial learning in a field especially difficult because the accepting framework is limited.

Slide 64

Find Time For Active: FLIP



- Homework: Lecture Notes w/clicker Q's, Memorize Flashcards, Apply to Problems
- Class: Homework quiz then Inquiry, overlearn, more practice, test.

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To find time to build automaticity, cognitive science recommends transferring a part of the delivery of lecture content to homework, so you have more time in class for active learning that builds links.

Slide 65

Why Textbook Reading Assignments Don't Work

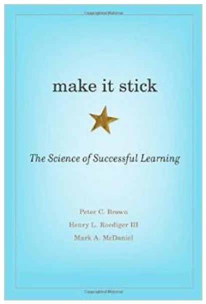
Summarize:

- When Sarwan and Chanderpaul were going on strongly, England were looking down the barrel. But they came back with Broad removing both of them within 8 overs of taking the 2nd new ball. It was always going to be difficult to survive with that kind of a batting line up and England then seemed to be on top. But the last pair hung around for ages to ensure that light is offered and they walk off.

Some of you might say: Why type up lecture notes? Why not have them read the text? Let's see what that's like for students. Summarize this paragraph. Raise your hand when your summary is ready.
Don't all raise your hands at once.
What's the problem? Which words in this passage are difficult? Is the problem difficult words, or a framework with their associations?
Comprehension studies say this is what a standard gen chem textbook looks like to most first-year students.

Slide 66

What does NOT work?



Inefficient at constructing LTM:

- Re-Reading
- Highlighting
- Cramming

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Make It Stick documents that these strategies are a poor use of time devoted to study. Which strategies do your students tend to use?

Slide 67

Summary: Cog Experts Say

To solve problems,

- *First,* memorize needed facts and algorithms
- *Then*, reason with them; Apply in multiple contexts; space overlearning.

Goal: Automaticity in Cued Recall

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The key principle is: Memorize, then reason.

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If you tell students: “Don’t memorize. Reason,” what happens?

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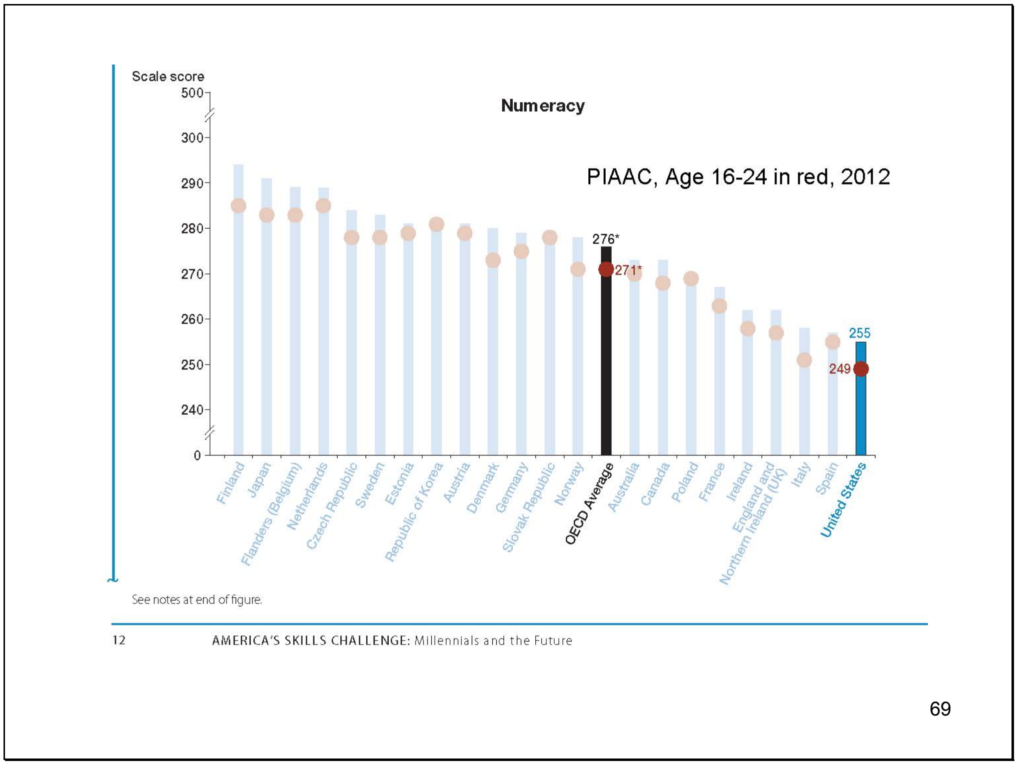
Slide 69

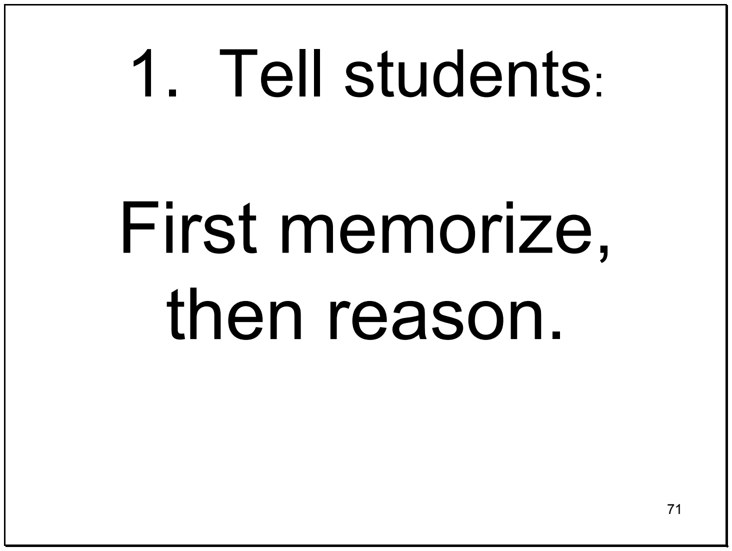


It was not anyone's fault, but back in 1990, before technology came on line to help us study the brain, most states (and some science educators) guessed wrong on how the brain worked.

Slide 70

15 years ago, educators thought students could reason with what had NOT been memorized. Since then, science has discovered that the brain is limited almost exclusively to reasoning with what has been well memorized. How can we use this new knowledge to help students?

Slide 71



Three suggestions: First, explain to your students how learning works.
Let them know they need to memorize, *then* apply, new facts and problem-solving procedures,
Then memorize and apply again, repeatedly, to construct memory.

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2. Design Instruction to Implement:

First memorize, then apply.

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How can you do this?

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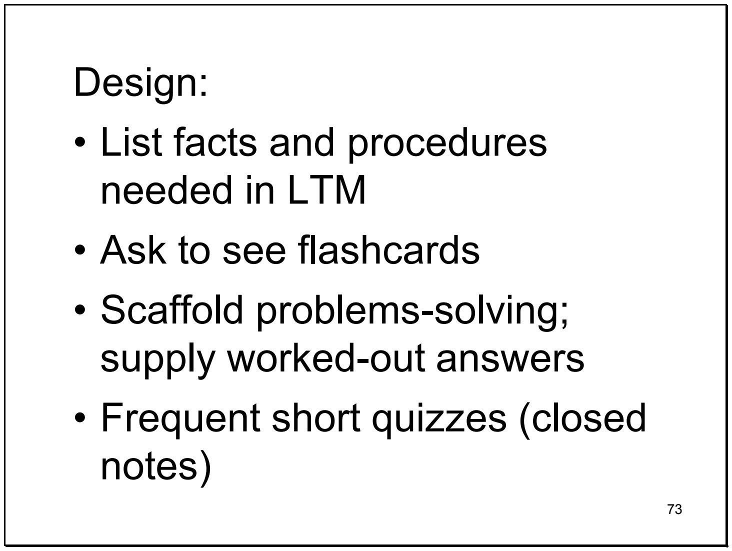

Experts in cognition recommend these steps.

Slide 74

3. Require: Overlearn Pre-reqs First

- ID (esp. math) pre-reqs for a topic
- Quiz to assess automaticity
- If needed, overlearn and re-quiz

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In chemistry, automating math before teaching “math with units attached” is especially important.
Because of state standards that de-emphasized computation, to get students ready for general chem,
in “preparation for gen chem” courses, substantial time may need to be devoted to *overlearning* computation.

Slide 75

Science-Supported Unit Sequence

1. Give short quiz on pre-reqs.
2. IF needed on pre-reqs : Overlearning, practice, re-quiz.
3. Intro new topic with short demo/inquiry.
4. Homework: Lecture notes w/ clicker Q's, flashcards, overlearning, practice, quiz.
5. More active learning, tougher quiz.

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This is an instructional sequence that cognitive studies recommend for a new topic in science.
Mix in-class at home, in-class, at home, in-class.

Slide 77

Free Resources

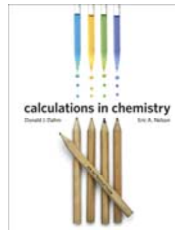
1. Download www.ChemReview.Net/WeekOneFiles.pdf
   - 50 pages of homework assignment options;
   - FREE for you and students
   - Week1-2 options for all first-year levels
   - Lecture notes with clicker questions
   - Worked-out practice, how to learn

When you have a minute, take a look at this free packet.

Slide 78

Free

2. Get a FREE book from WWNorton:
   - 560 pages HS or Prep or GOB/nursing Chem, *or*
   - 1,250 pages for Prep, AP, General, Engineering, GOB/Nursing



- Homework ideas that build automaticity.
- Free to instructors: http://chemreview.net/blog/?page_id=46

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Get one of these free books with homework assignment ideas that promote overlearning.

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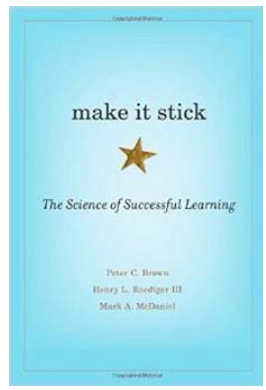
More Resources

3. More on how the brain works, free, at

   www.ChemReview.Net/CogSciForChemists.pdf

   www.ChemReview.Net/blog

4. $22 →



The citations for my slides, plus lots more on cognitive science, are on the web at Point 3 above -- and in a new post at http://arxiv.org/abs/1608.05006

And finally, you will find *Make It Stick* very helpful on ways to teach students to learn. We have recently learned much, and are learning more, about what works in learning.

Slide 80

To Learn:
First memorize, then reason.

- Done!
- What’s the ONE thing to remember?
- Sceptical Questions?
- Opposing viewpoints?

# # # # #