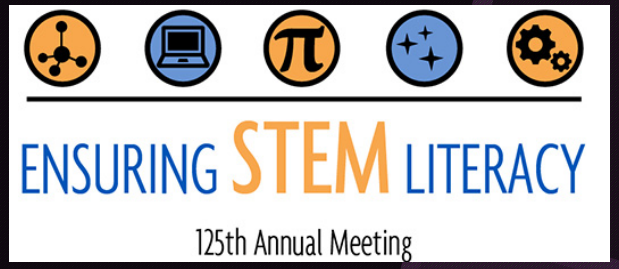
Science Literacy's Neglected Twin: Numeracy

Kate Follette and Don McCarthy

6 cups a day? Coffee lovers less likely to die, study finds

$$L_* = 4\pi R_*^2 \sigma T_*^4$$



- Introduction
- Skills and attitudes
- A real assessment of student skills
- Why emphasize numeracy?
- Can you make a difference?

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Don McCarthy

Warmup Problem

Derive the Ideal Gas Law

$$P_g = nkT$$

Begin with the pressure integral

$$P = \frac{1}{3}\int_0^\infty mn_v v^2\, dv$$

And the Maxwell-Boltzmann velocity distribution function

$$n_v dv = n\left(\frac{m}{2\pi kT}\right)^{3/2} e^{-mv^2/2kT}\, 4\pi v^2 dv$$

Discuss with your neighbor how to approach this problem.

How Did This Problem Make You Feel?

- Introduction
- Skills and attitudes
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- Why emphasize numeracy?
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a) Challenged

b) Intrigued

c) Frightened

d) Inadequate

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An Astro 101 Classroom Parallel

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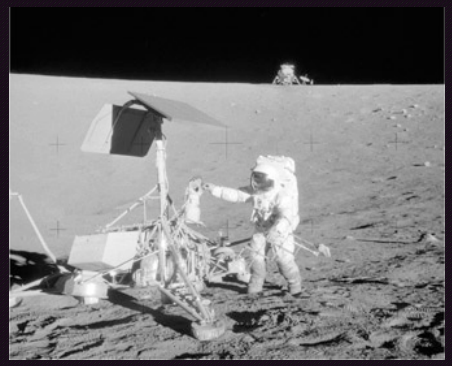

Your Weight on Another World

The Moon's mass is 81x less than Earth's, so you might expect to weigh 81x less on the Moon.

However, your weight on the Moon would really be about 6x less than on Earth. Why?

Here are some numbers and an equation that might prove useful:

$G = 6.6738 \times 10^{-11}\ m^3\ kg^{-1}s^{-2}$

$m_{Earth} = 5.972 \times 10^{24}\ kg$

$r_{Earth} = 3{,}959\ mi$

$r_{Moon} = 1{,}080\ mi$

$$F_G = \frac{Gm_1m_2}{r^2}$$

How Do Your Students Feel?

- Introduction
- Skills and attitudes
- A real assessment of student skills
- Why emphasize numeracy?
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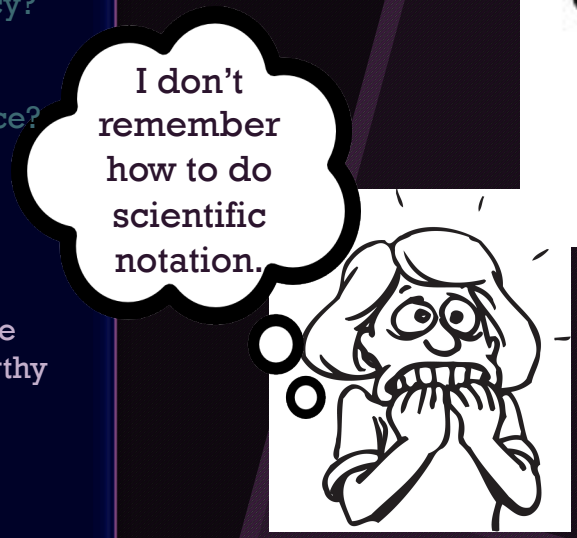
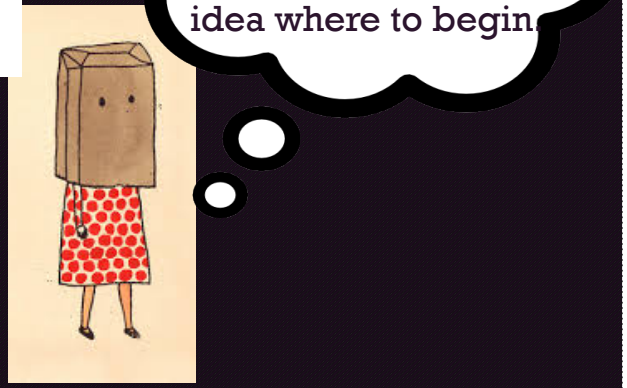
-2





- ✧ Introduction
- ✧ Skills and attitudes
- ✧ A real assessment of student skills
- ✧ Why emphasize numeracy?
- ✧ Can you make a difference?

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Today's Emphasis

✧ Introduction:
- Ourselves
- What is "Quantitative Literacy"?
- Why should you care?

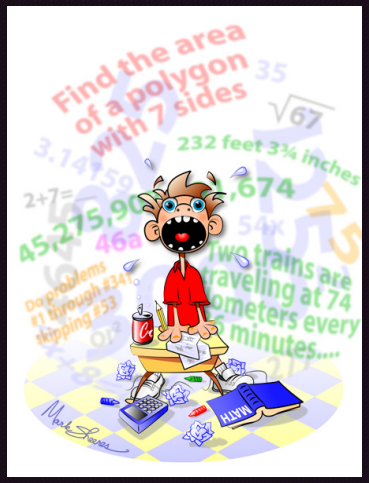
✧ The problems:
- Numerical deficits
- Ignorance of its value

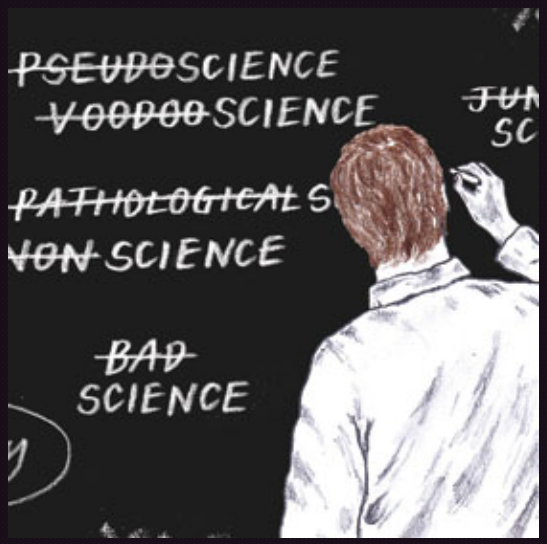
✧ Can an Astro 101 course improve numerical skills and attitudes?

✧ Can you make a difference?

Kate's Motivation

- Introduction
- Skills and attitudes
- A real assessment of student skills
- Why emphasize numeracy?
- Can you make a difference?





$$F_G = \frac{Gm_1m_2}{r^2}$$

COSMOS IN THE CLASSROOM 2010

EARTH AND SPACE SCIENCE: MAKING CONNECTIONS IN EDUCATION & PUBLIC OUTREACH

JULY 31–AUGUST 4, 2010 • UNIVERSITY OF COLORADO AT BOULDER

ASTRONOMICAL SOCIETY OF THE PACIFIC/GEOLOGICAL SOCIETY OF AMERICA

Kate Follette
Don McCarthy

Kate Follette
Don McCarthy

Don's Motivation

- I want to teach more depth in college science.
- Are we:
  - dumbing down "science" ?
  - failing to prepare students for jobs and citizenship?
- Basic skills I desire are the same in many careers and citizenship.
- Make students more aware of their poor skills and the value of arithmetic.
- Foreigners use quantitative thinking instinctively.

OPINION | November 14, 2012, 6:17 p.m. ET

Arthur Levine: The Suburban Education Gap

The U.S. economy could be $1 trillion a year stronger if Americans only performed at Canada's level in math.

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Numeracy
Quantitative Literacy

…. the ability to **reason with** numbers, graphs, statistics, etc. in order to be an effective participant in modern society

"Quantitative literacy involves sophisticated reasoning with elementary mathematics more than elementary reasoning with sophisticated mathematics."

Steen, 2004

"an innumerate citizen today is as vulnerable as the illiterate peasant of Gutenberg's time"
Lynn Steen

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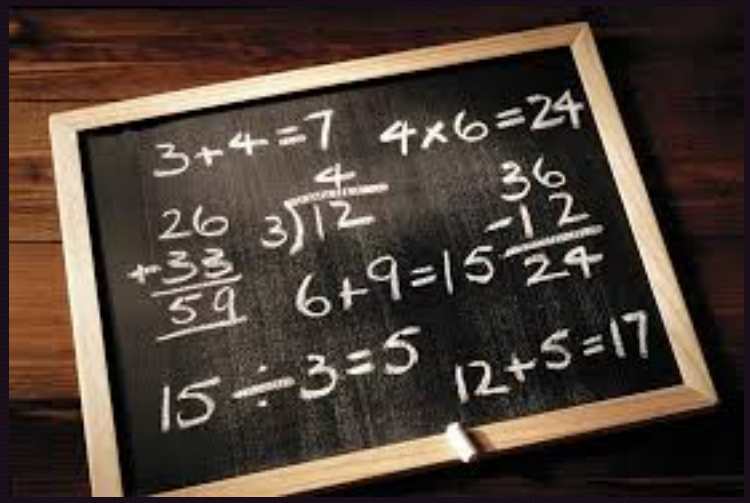
Problem #1



Students have not mastered 5-7th grade arithmetic.

Table 1. Common mathematical misconceptions encountered frequently in our classrooms.

Operation	Common Incorrect Answer
1 ÷ 5	0.5
0.5=	5%
How many seconds in an hour?	60sec/min + 60min/hr = 120sec
10^2=	20
4.3×10^6=	4.3000000

Grade 6 Math Standards

- ✧ Introduction
- ✧ Skills and attitudes
- ✧ A real assessment of student skills
- ✧ Why emphasize numeracy?
- ✧ Can you make a difference?

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Ratios and Proportional Relationships (RP)

- Understand ratio concepts and use ratio reasoning to solve problems.

The Number System (NS)

- Apply and extend previous understandings of multiplication and division to divide fractions by fractions.
- Compute fluently with multi-digit numbers and find common factors and multiples.
- Apply and extend previous understandings of numbers to the system of rational numbers.

Mathematical Practices (MP)

1. Make sense of problems and persevere in solving them.
2. Reason abstractly and quantitatively.
3. Construct viable arguments and critique the reasoning of others.
4. Model with mathematics.
5. Use appropriate tools strategically.
6. Attend to precision.
7. Look for and make use of structure.
8. Look for and express regularity in repeated reasoning.

- surface area, and volume.

Statistics and Probability (SP)

- Develop understanding of statistical variability.
- Summarize and describe distributions.

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Unaware of Their Skills

~50% are confident in incorrect answers

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Stages in Learning

"They're not Dumb, They're Different"
Tobias

EXPERT

unconscious competence

conscious competence

conscious incompetence

unconscious incompetence

NOVICE

- Introduction
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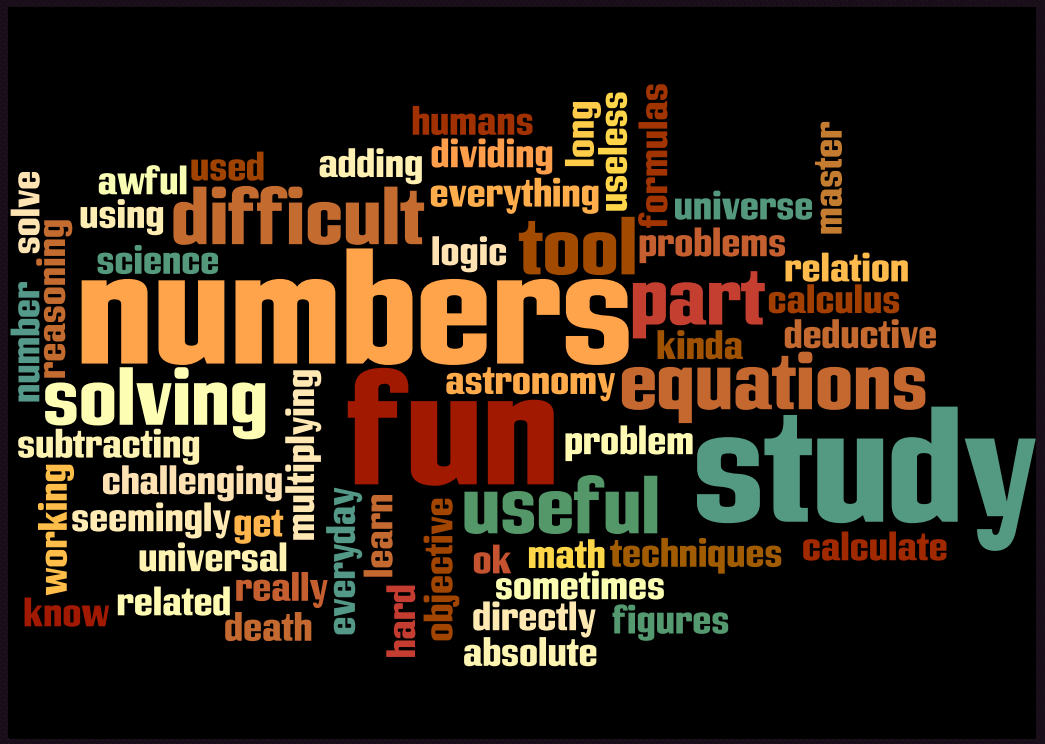
Problem #2: Math is …

Students do not view math as relevant or valuable to them.



"The only purpose of math is to pass a test in math class."

- ✧ Introduction
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Causes

✧ "Math Anxiety"

✧ Math is taught mechanically, not as a language with meaning.

- *"I can't divide one by a half."*

  (Honor's student - university)

✧ Math is not reinforced across the curriculum (K-12+).

- *"I have never seen math and science used together."*

  (Honor's student – middle school)

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What About You?

How often do you emphasize quantitative science in your class or outreach activities?

a) Every class/activity

b) Occasionally

c) Rarely

d) Never

- Introduction
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What About You?

What is the biggest barrier or difficulty for you in incorporating quantitative skills into your class or outreach activities?

a) Students' lack of skill

b) Students' anxiety

c) My own anxiety

d) Lack of time

e) Worry that it will take away from the science

"I don't know what it is with US students and math, but in my class, I basically have to dilute the math content or I wouldn't have any students."

Tony George
Astronomy Instructor

- Introduction
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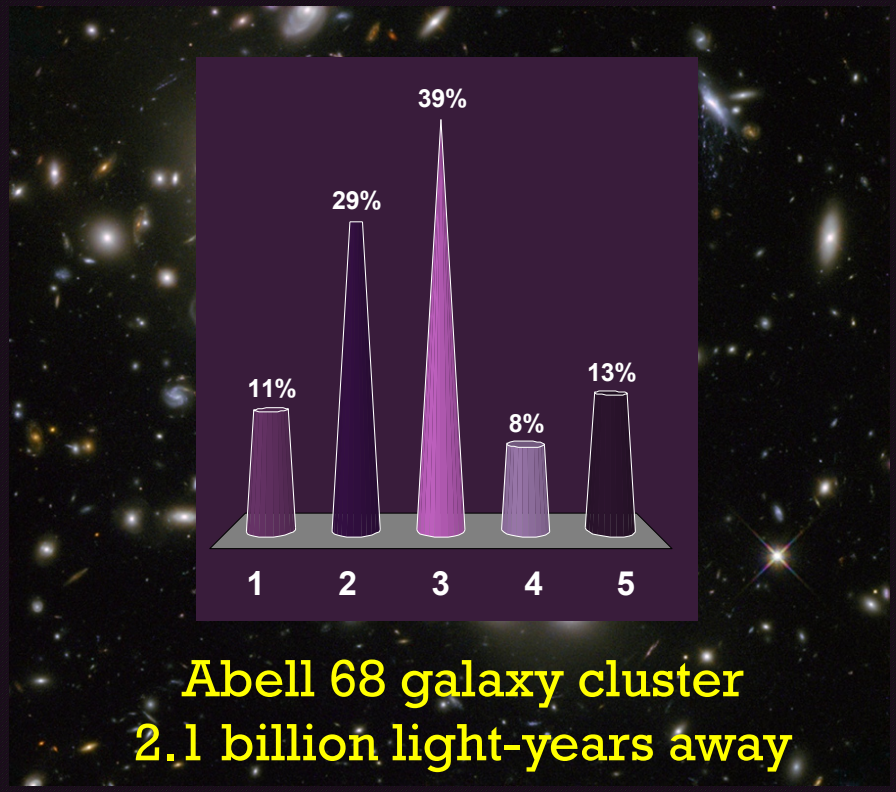
What About You?

Are we "unconsciously competent"?
Our language may not be familiar.



Abell 68 galaxy cluster
2.1 billion light-years away

Where is one billion on this scale?

trillion — 1

A B C D E

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What About You?

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Our language may not be familiar.

GSUSA presentation at a local conference
millions or billions?

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QL Instrument

Skills Addressed

- Area
- Comparison of numbers
- Graph reading and interpretation
- Error
- Estimation
- Fractions and percentages
- Simple arithmetic

Our Sample

- 10 classes
  - 6 small (25-35)
  - 3 large (100)
  - 1 very large (800+)

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Sample Question

70% correct Pre
75% correct Post

A sign promotes a 30% off sale on a $100 sweater .

You have two coupons :

One for an additional 25% off the sale price.
One for an additional $25 off the sale price.

Which coupon yields the lowest price?

a) The 25% off coupon
b) The $25 off coupon
c) It doesn't matter. Either one will give you the same final price.

How confident are you in the answer you just selected?

a) very confident
b) confident
c) not very confident
d) I guessed

A Graphing Problem

- Introduction
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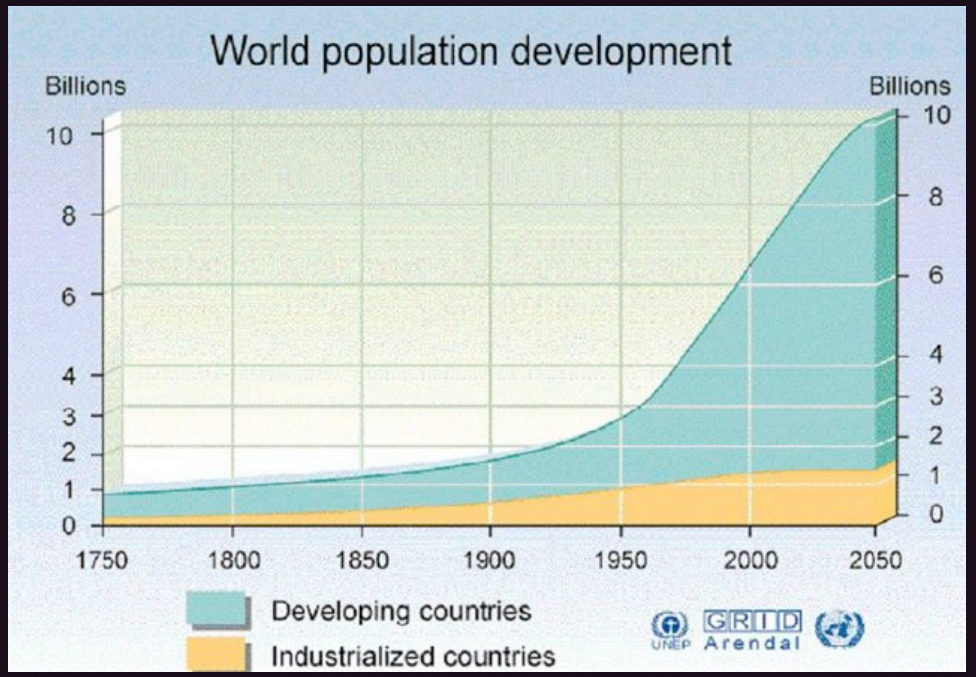

Average Score 37%

QL Skills Instrument

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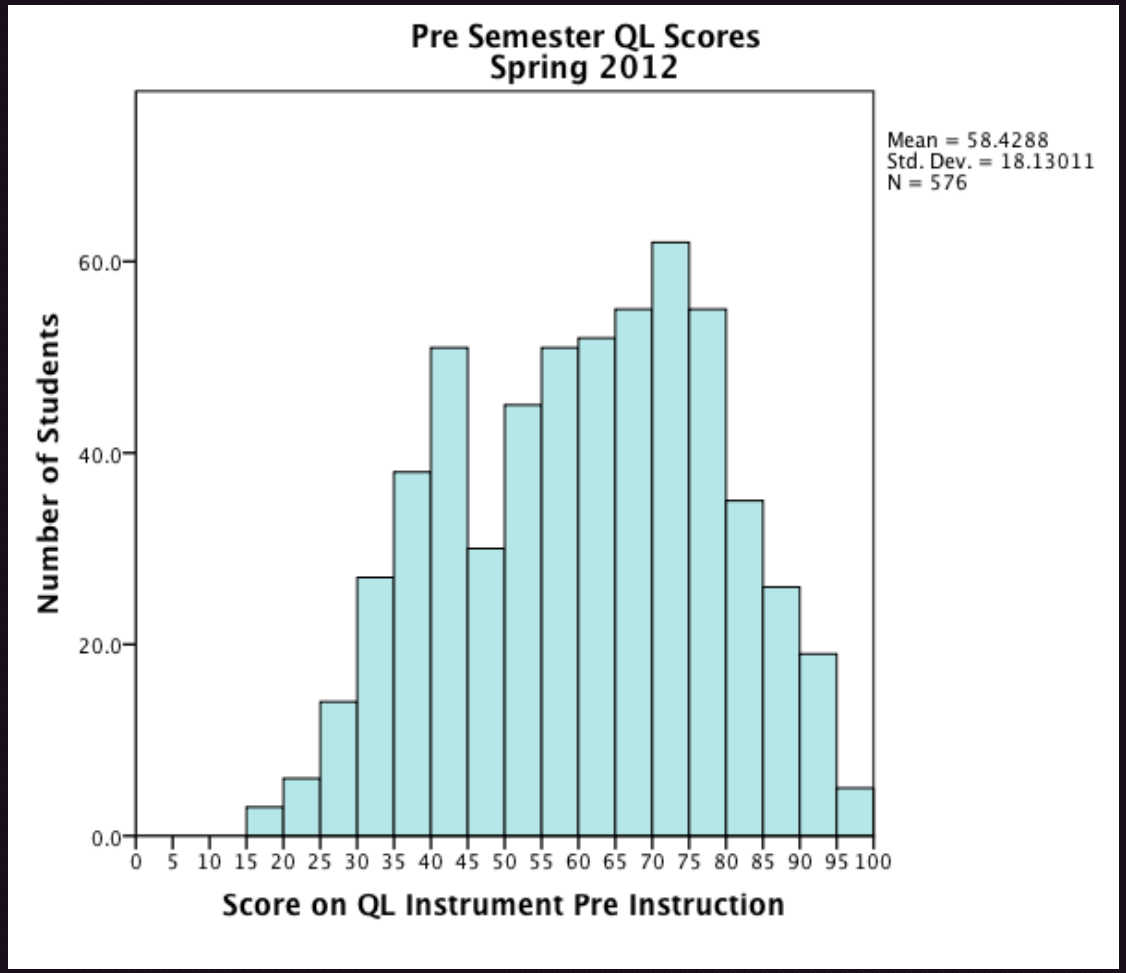

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Initial Results

Class 1

Pre: 62.7% (N=145)
Post: 63.6% (N=122)
Gain: 0.04 (N=108)

Class 2

Pre: 66.5% (N=20)
Post: 74.2% (N=13)
Gain: 1.15 (N=13)

Class 3

Pre: 66.9% (N=13)
Post: 66.8% (N=14)
Gain: -0.23 (N=13)

Classes 4,5,6

Pre: 56.3% (N=72)
Post: 60.2% (N=30)
Gain: 0.07 (N=29)

Class 7

Pre: 57.3% (N=416)
Post: 56.0% (N=336)
Gain: -0.23 (N=299)

Quantitative Biology

- Introduction
- Skills and attitudes
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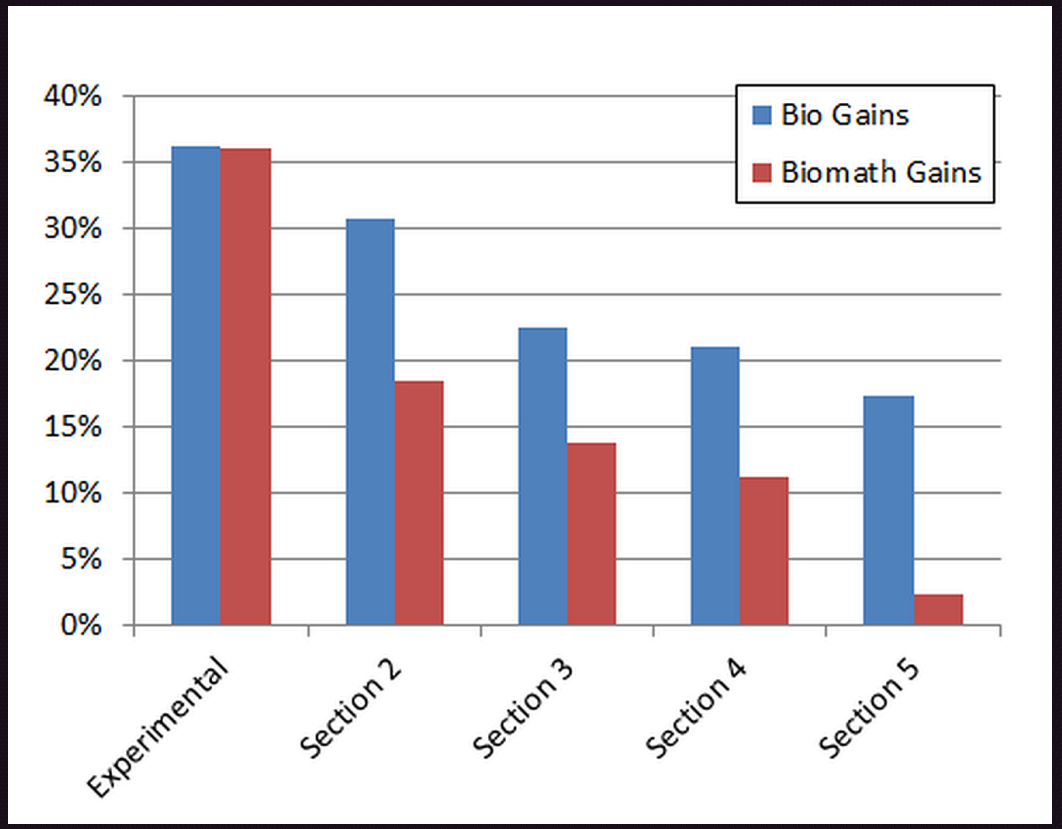

Hester, Buxner et al. 2013, submitted
CBE – Life Sciences Education

- ✧ Introduction
- ✧ Skills and attitudes
- ✧ A real assessment of student skills
- ✧ Why emphasize numeracy?
- ✧ Can you make a difference?

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Initial Results

Suspected Issues

- ✧ Class size
- ✧ Attrition
- ✧ Late-semester apathy
  - ✧ Average time pre = 24 min
  - ✧ Average time post = 20 min
- ✧ Instrument quality

Results are consistent with experience of James Milgram (Stanford mathematician, educator, consultant)

> *"The first was some courses I gave in New Mexico, where I had too many bright, very highly motivated students in my mathematics classes whose third rate K - 12 educations in mathematics could not be overcome no matter how hard these students were willing to work."*

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Initial Results

Class 1 (N=145,122)

Adjective	Pre to Post Change
Interesting	5.66%
Useful	2.72%
Useless	-1.09%
Boring	-4.19%
Hard	-3.11%

Classes 2&3 (N=42,28)

Adjective	Pre to Post Change
Interesting	3.50%
Useful	7.73%
Useless	-3.11%
Boring	-6.11%
Hard	-2.00%

Classes 4,5 & 6 (N=72, 30)

Adjective	Pre to Post Change
Interesting	-9.94%
Useful	-2.43%
Useless	1.07%
Boring	10.38%
Hard	0.93%

Class 7 (N=416,336)

Adjective	Pre to Post Change
Interesting	3.09%
Useful	0.78%
Useless	-1.21%
Boring	-1.47%
Hard	-1.19%

- Introduction
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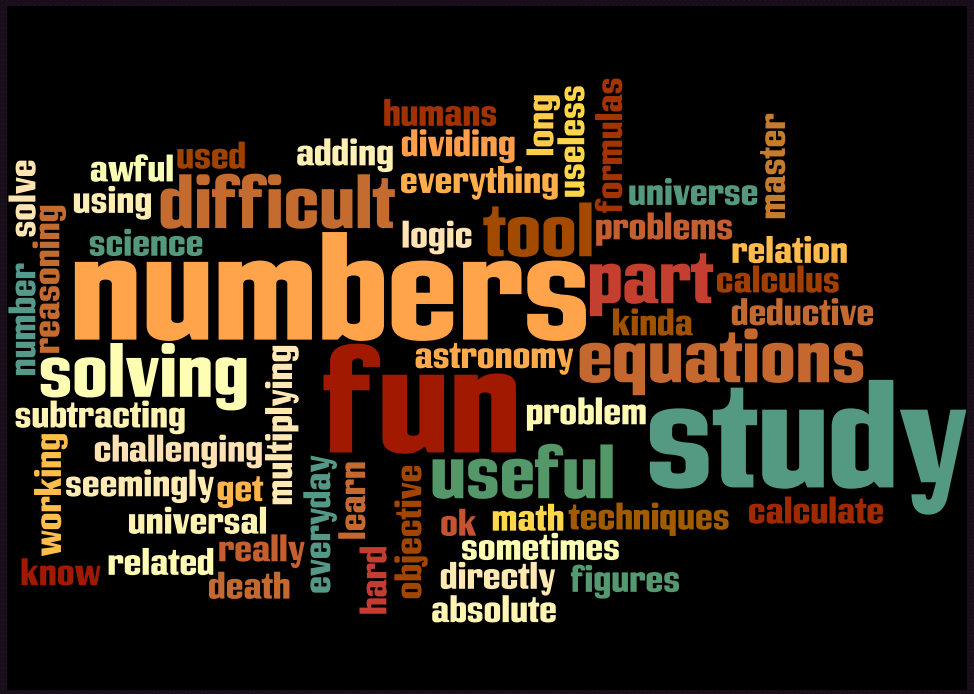
Math is . . .



"The most interesting thing that I have learned in this class, by far, is how small we are compared to the universe. I think that everybody knows there is a lot of space out there, but until you sit down and do some math about it you can't get an idea of how insignificant we are."

"I most enjoyed the use of math in this class. I knew science is based on math, but it really set in after this class."

Why Astro 101?

- Introduction
- Skills and attitudes
- A real assessment of student skills
- Why emphasize numeracy?
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"I have always heard a lot about science and math being related, but I have never actually used them together. I have finished an entire year of algebra, but there has never been any science in it. The same holds true in my science class. Frankly, I have never seen any connection between the two of them."

- AIP survey: "Introductory astronomy enrollments have remained in the 180,000-190,000 range since 2004." (Nicholson and Mulvey, 2010)
- Community colleges, where "an estimated 100,000 students take Astronomy 101 in departments not covered by the AIP survey." (Fraknoi 2001).
- >10% of college students eventually pass through the door of an "Astronomy 101" course in college.
- 5-10% of them are future educators (~30,000 !)

Voters, Consumers, Citizens

- Introduction
- Skills and attitudes
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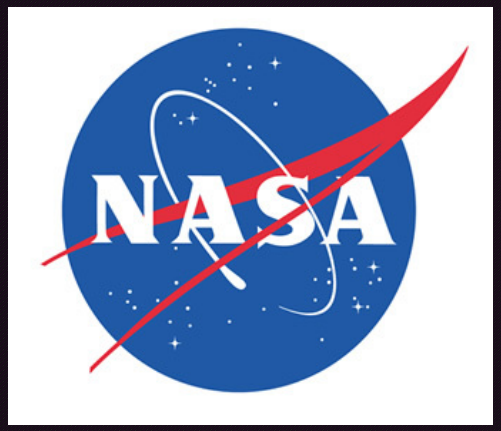

NASA's 2011 Budget:
$18.724 billion

US 2011 Budget:
$3.630 trillion

"There are 10^{11} stars in the galaxy. That used to be a huge number. But it's only a hundred billion. It's less than the national deficit! We used to call them astronomical numbers. Now we should call them economical numbers."

Richard Feynman
U.S. educator & physicist (1918 - 1988)

Help Avert Pseudoscience

- Introduction
- Skills and attitudes
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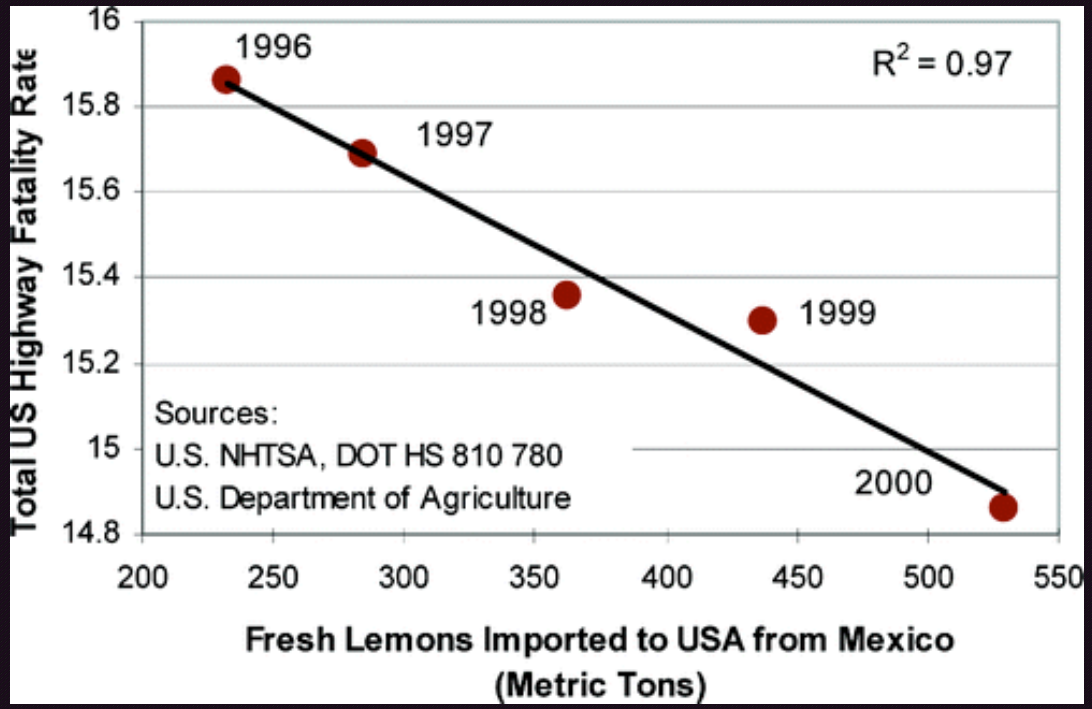
"I have here in my hand a list of 205, a list of names that were made known to the Secretary of State as being members of the Communist party and who nevertheless are still working and shaping policy in the State Department."
Joseph McCarthy (1950)



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What Can We Reasonably Do?

While teaching astronomy, we can …

- ✧ model the value of numbers in daily life.
- ✧ change attitudes, build awareness and motivation.
- ✧ reduce anxiety and build confidence.
- ✧ provide opportunities for improvement.

Is there a better way?

- Introduction
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Science News ... from universities, journals, and other research organizatio

Fast and Painless Way to Better Mental Arithmetic? Yes, There Might Actually Be a Way

May 16, 2013 — In the future, if you want to improve your ability to manipulate numbers in your head, you might just plug yourself in. So say researchers who report in the Cell Press journal *Current Biology* on May 16 on studies of a harmless form of brain stimulation applied to an area known to be important for math ability.

enlarge

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"With just five days of cognitive training and noninvasive, painless brain stimulation, we were able to bring about long-lasting improvements in cognitive and brain functions," says Roi Cohen Kadosh of the University of Oxford.

- ✧ Introduction
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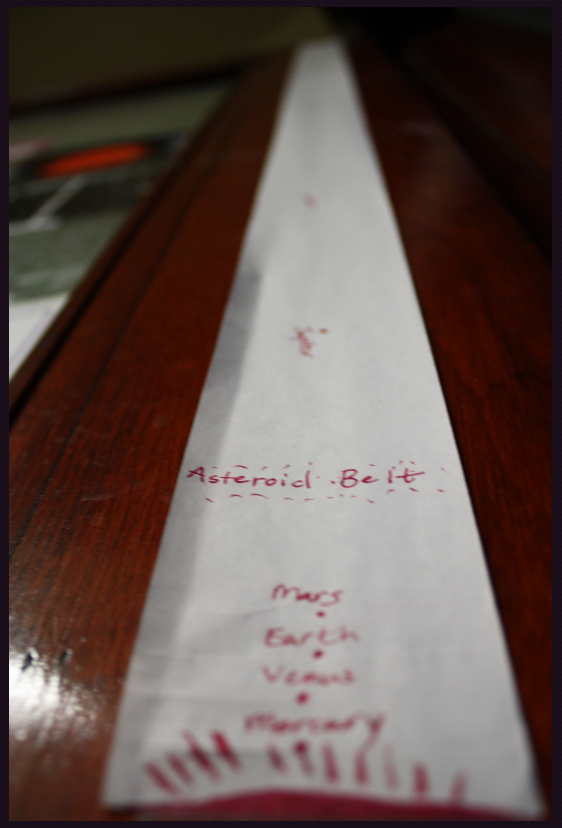
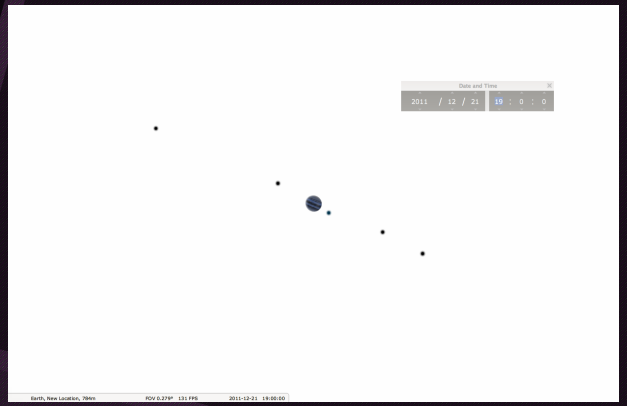
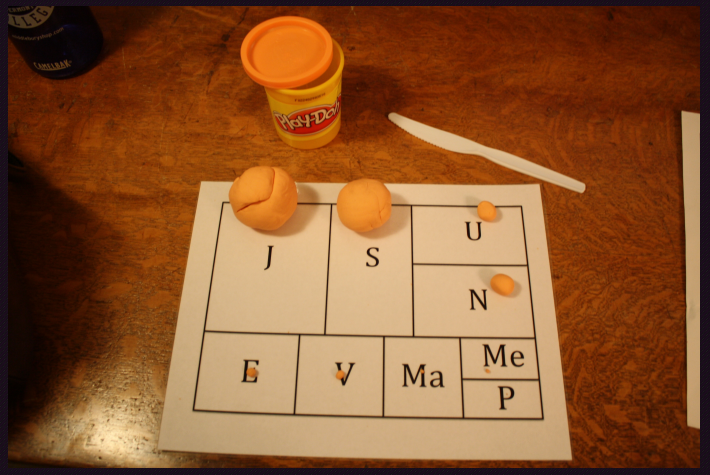
Kate's Workshop

✧Numerically rich TPS questions

✧Labs/Activities with QL emphasis







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Don McCarthy

Don's Workshop
Language of Numbers

- Introduction
- Skills and attitudes
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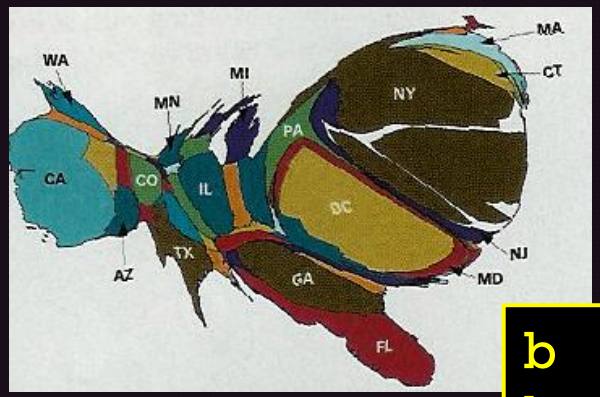
Study: Dementia Prevented By Working Longer And Delaying Retirement

Published July 16, 2013 / Fox News Latino



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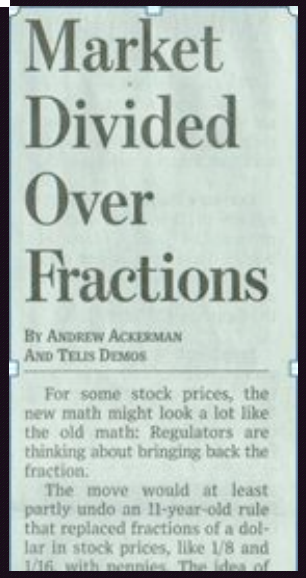


Market Divided Over Fractions

By Andrew Ackerman And Telis Demos

For some stock prices, the new math might look a lot like the old math: Regulators are thinking about bringing back the fraction.

The move would at least partly undo an 11-year-old rule that replaced fractions of a dollar in stock prices, like 1/8 and 1/16, with pennies. The idea of

Bad math ?

5 + 6 = 11

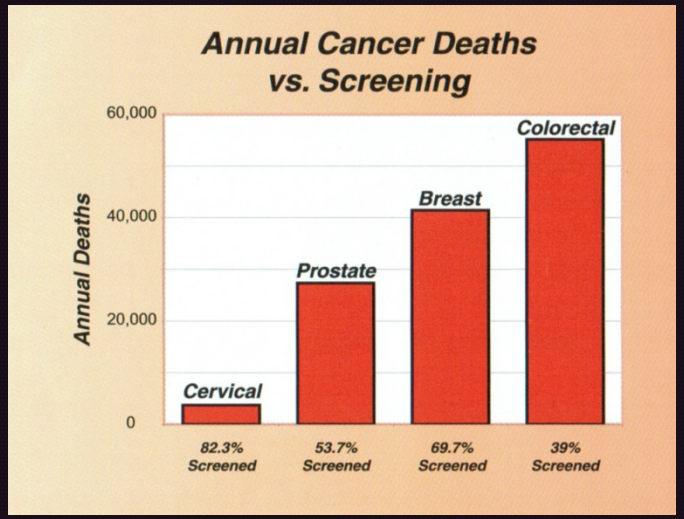
7 + 8 = 3

9 + 10 = 7

11 + 11 = 10

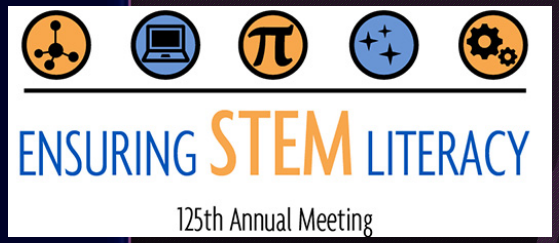
$$L_* = 4\pi R_*^2 \sigma T_*^4$$

"Arithmetic is generally taught as all scales and no music."
Peris Herold



THE LATEST

- NEW Rowling book sales soar 507,000%



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- A real assessment of student skills
- Why emphasize numeracy?
- Can you make a difference?

Kate Follette
Don McCarthy

Summary

- Innumeracy has serious implications for science literacy, and students' ability to spot pseudoscience in particular.
- Numbers are an important component of both science and citizenship.
- Intro science courses for non-majors capture an important innumerate demographic.
- Our students' skills are worse than you think!
  - Students have a false sense of their abilities and the value of numerical skills.
- It is possible to change attitudes and to provoke awareness of need to improve.
- It may be possible to improve skills.

- Introduction
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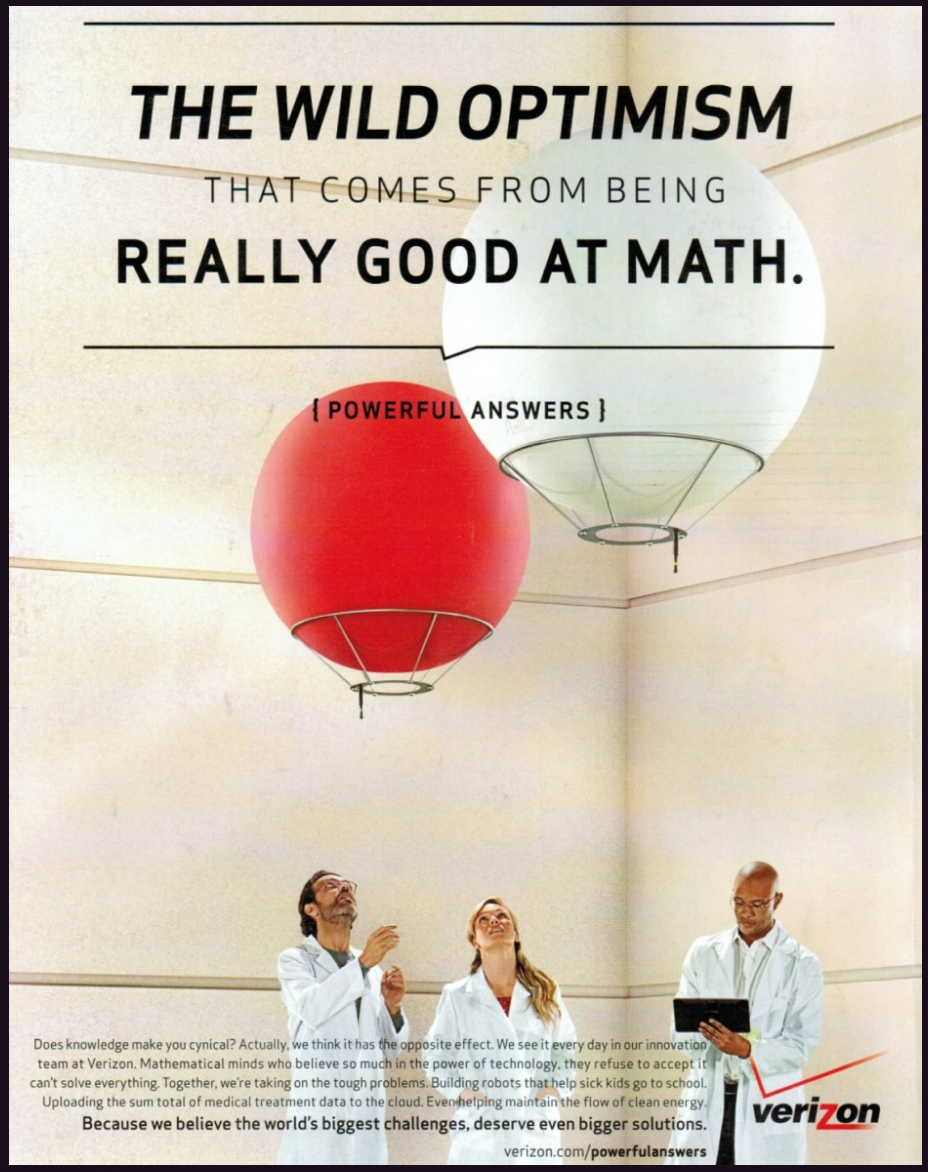
Let's help students get to this level.



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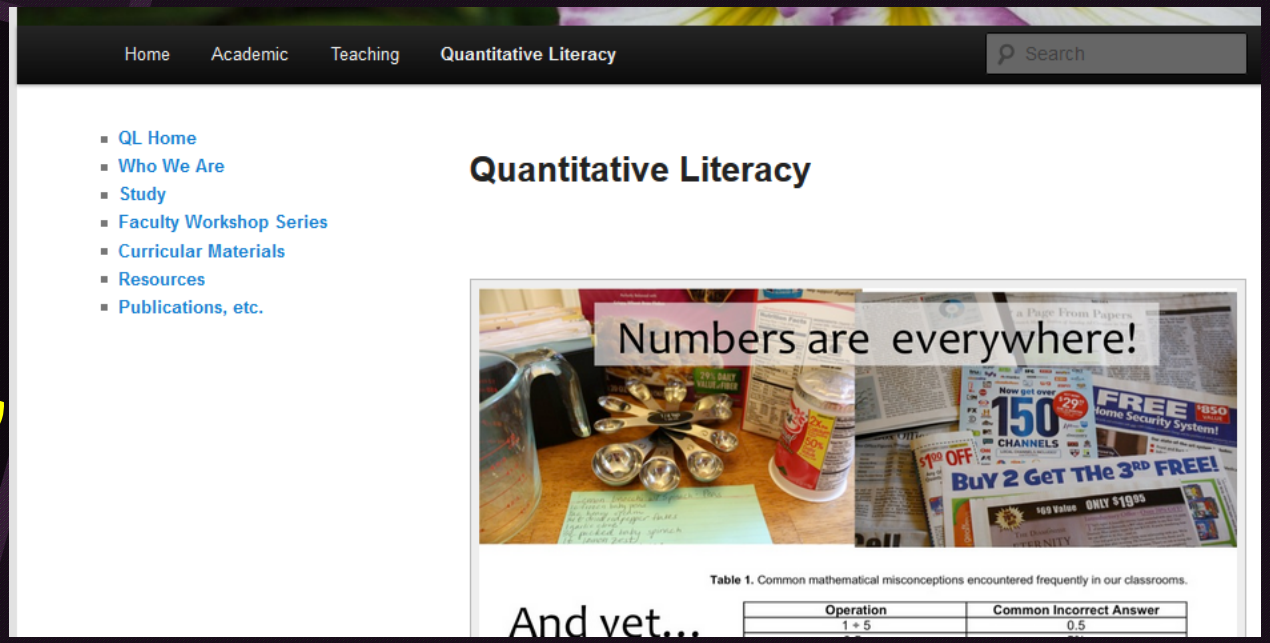
Our Website



www.katefollette.com/QL

Please come to our workshops to learn more!

Time: Tuesday 4:30 p.m. – 5:30 p.m.

Session Type: Cosmos 1-Hour Workshop
(SPECIAL SESSION)
Conference Thread: Innovations and Great Ideas for the Classroom
Location: Almaden

C6A RE-NUMERATE: Restoring Essential Numerical Skills and Thinking in Astronomy Education

Wednesday, July 24, 2013 • 4:30 – 5:30 p.m.

Session Type: Cosmos 1-Hour Workshop
(SPECIAL SESSION)
Conference Thread: Innovations and Great Ideas for the Classroom
Location: Costanoan

C10B RE-NUMERATE: Cross-Curricular Techniques to Restore Essential Numerical Skills in Science Education

Kate Follette
Don McCarthy

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dmccarthy@as.arizona.edu

Check out our Website:

www.katefollette.com/QL

THANK YOU!

- Motivation
- Study Basics
- Preliminary Results
- Implications and Future Plans

Step 4: Faculty Training and Awareness

- Astronomical Society of the Pacific, 2011
  - Hilighted poster
  - Contributed article to Mercury Magazine
- American Astronomical Society 2012
- Astronomical Society of the Pacific, 2012
  - Panel Discussion
  - 1hr workshop
- American Astronomical Society
  - 2hr workshop

Kate Follette
University of Arizona
NNN 2012
October 13, 2012

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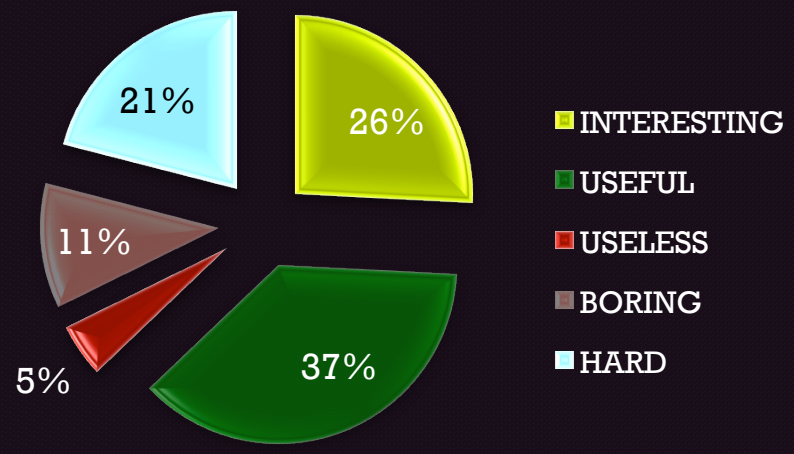
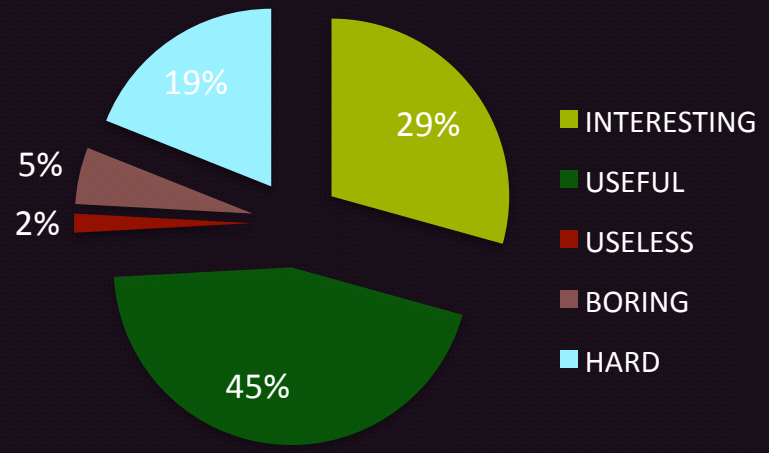
Math is …





2 semesters, n=60

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Problem #1

Students have not mastered 5-7th grade arithmetic.

Poor Performance

- Fractions – decimals – ratios - percentages – powers of ten
- 0.3 = 1/3
- "10% off price" is a challenge.
- Graph reading and interpretation
- Error estimates
- Do not know HOW to determine seconds in an hour
- Non-linear and "inverse-square" seem too advanced
- Hard to consider more than one variable.

Math Anxiety

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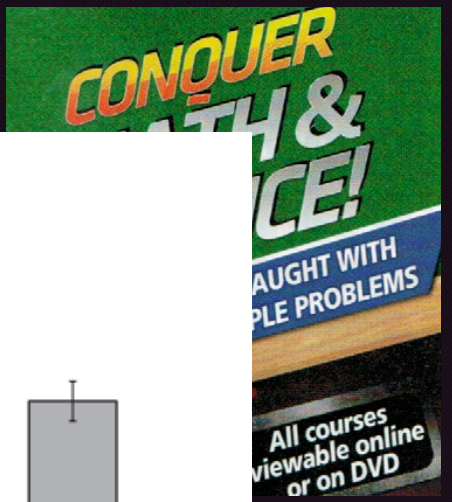
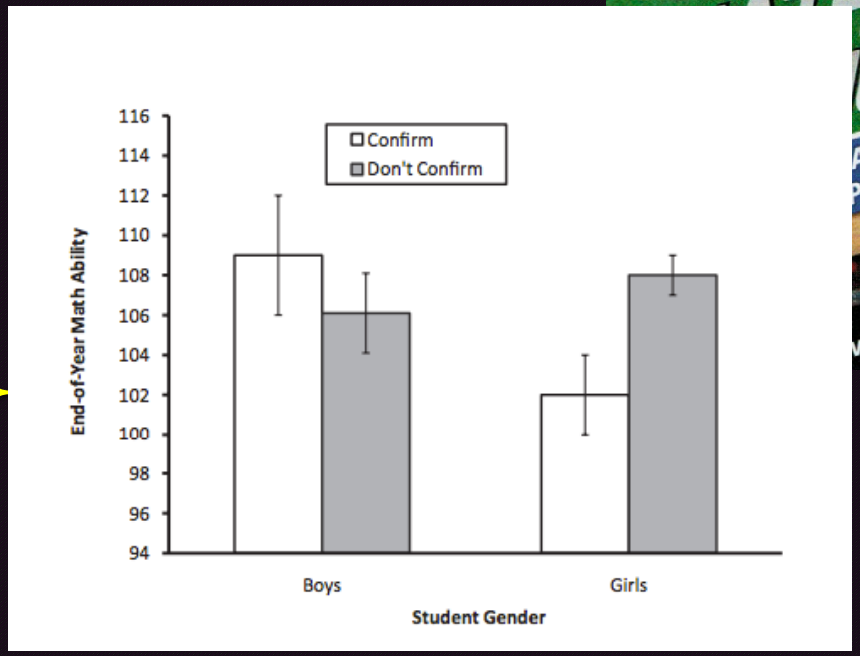
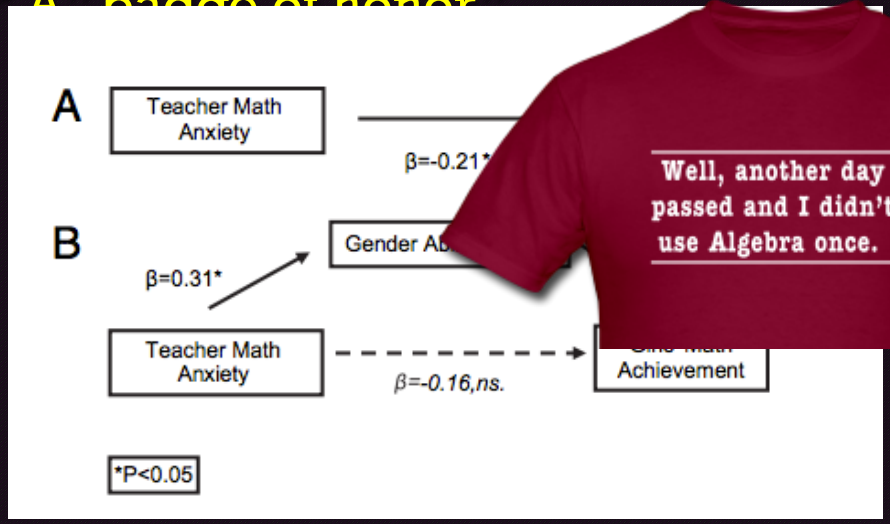




- A" badge of honor"



Students avoid math at all costs!