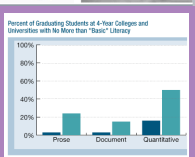
How We Serve (or Underserve) Our Students through 'Dumbing Down': Improving Skills in Quantitative Literacy via Introductory Astronomy

Dr. Don McCarthy and Kate Brutlag Follette

Motivation

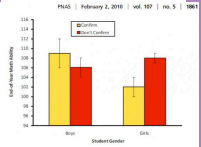
The National Assessment of Adult Literacy surveyed 26,000 American adults in the areas of prose, document and quantitative literacy in 1992, with a follow-up in 2003. This NALS defined quantitative literacy as "the knowledge and skills required to apply arithmetic operations, either alone or sequentially, using numbers embedded in printed materials; for example, balancing a checkbook, figuring out a tip, completing an order form, or determining the amount of interest from a loan advertisement", and included among the key results were the following conclusions:
1.more than 20% of American adults performed at the lowest level of quantitative proficiency, and an additional 25% of adults demonstrated the next highest degree of proficiency. Both levels indicate an inability to perform more than a single operation or use more than one number from a document to determine information.
2.The quantitative proficiency of younger adults was lower than that of older adults, suggesting that the general numerical proficiency of the
3.US population is declining with time.
4.Individuals with the highest numerical proficiencies reported weekly wages 2-3 times higher than individuals in the lowest levels and were more likely to be employed.
5.Black, American Indian/Alaskan Native, Hispanic, and Asian/Pacific Islander adults were more likely to perform in the lowest two levels than White adults.
6.The quantitative proficiencies of men were somewhat higher than those of women.
7.Adults with physical, mental or other health conditions were more likely to perform in the lowest two levels of proficiency.
Conclusions (4) through (6) regarding at risk populations have also been revealed in other studies. Particularly relevant are results suggesting that: women are more susceptible to math anxiety (Betz 1978), minorities are more likely to leave college with deficits in numeracy (Raudenbush and Kasim, 2009, Ogbu 1990), and that students with learning difficulties are particularly likely to struggle with applied mathematics (Chan and Dally 2001, Rousselle and Noel 2007).
We are also acutely aware that many (up to 15% according to initial survey responses) of our non-major students are pre-service teachers, and we feel that this is another particularly important classroom demographic to study. The literature suggests that many people learn 'math anxiety' from their teachers (Beilock et al., 2009, Jackson and Leffingwell 1999), so leaving this group of students with, at the least, an improved attitude toward mathematics is a very important step towards mitigating math anxiety and improving quantitative literacy in future generations.



Above: Examples of the many ways in which modern society is swimming in quantitative information
Left: Results from the NALS, showing that QL is a particularly dire problem among college graduates, particularly minorities
Below: Results from a study showing correlation between math anxiety and whether or not girls conform to the gender stereotype that "boys are good at math"

Prose: Comprehending and using information from texts such as news stories and editorials.
Document: Comprehending and using information from documents such as job applications and maps.
Quantitative: Identifying and performing computations using numbers embedded in printed materials such as an interest rate schedule.

Source: J.O. Baer, A.L. Cook, S. Baldi, The Literacy of America's College Students, American Institutes for Research, 2006.



Math achievement scores (standardized based on students' age) at the end of the school year for boys and girls as a function of whether they confirmed common gender ability beliefs (drew a boy to depict a student good at math and a girl to depict a student good at reading: Confirm) or did not (Don't Confirm)

"Teachers must encourage [students] to see and use mathematics in everything they do… Only by encountering the elements and expressions of numeracy in real contexts that are meaningful to them will students develop the habits of mind of a numerate citizen. Like literacy, numeracy is everyone's responsibility" ([1] "The Case for Quantitative Literacy"),

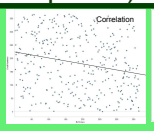
"Although the mathematical foundation of quantitative literacy is laid in middle school, literacy can only be developed by a continuous, coordinated effort throughout high school and college. . . Mathematicians have a lot of work to do to convince students that they are teaching something useful. Having faculty outside mathematics include quantitative problems in their own courses is extremely important. These problems are much more likely to be considered realistic" ([2] Hallett)

"Why I Want to Go to Astronomy Camp"
" Astronomy Camp will be a fun and interesting way to introduce myself to science the way it is actually done. … 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 never has there 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. Hopefully I will be able to use more advanced math and science together at Astronomy Camp...."

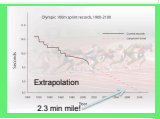
Common Mathematical Misconceptions (and Deceptions)

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

Operation	Common Incorrect Answer
1 ÷ 5	0.5
0.5²	5%
How many seconds in an hour?	60sec/min + 60min/hr = 120sec
10^2	20
4.3×10^{-6} =	4.3000000

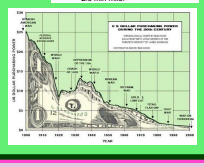


Studies suggest that innumerate adults are less successful at managing their own health (Schwartz et al. 1997, Apter et al. 2009, Brown et al. 2010), understanding the informed consent process (Couper and Singer 2009) and comprehending other forms of risk-benefit analysis (Peters et al 2007, Peters et al 2010).



Numbers and data are everywhere in modern society! As educators, we must instill in our students the skills necessary to distinguish B.S. from reality and help them reach the level of mathematical sophistication needed to be discerning consumers, voters and citizens!

"Comparing Apples to Oranges"
"Throughout the first 224 years (1776-2000) of our nation's history, 42 U.S. presidents borrowed a combined $1.01 trillion from foreign governments and financial institutions according to the U.S. Treasury Department. In the past four years alone (2001-2005), the Bush administration has borrowed a staggering $1.05 trillion"
-The 'Blue Dog Coalition' of House Democrats November 2, 2005



Workshop Series

"One [difficulty in cross-curricular implementation of QL] is the notion of 'special expertise'… A major challenge in implementing writing across the curriculum, for instance, is the fact that faculty do not all know automatically how to coach or assess writing effectively, so substantial efforts at faculty development are generally required I believe the same level of effort is required for quantitative literacy." ([1] Ewell).

We have begun development of a workshop series on "Techniques, Tools and Tips for Improving Quantitative Literacy in the Science Classroom". We see the goals of such a program as threefold
a) To raise awareness of the problem of serious deficits incoming college students have in the area of mathematical reasoning
b) To share evidence-based tips, tricks and curricular materials that we have collected and developed, which will be increasingly informed by the results of our study
c) To recruit instructors interested in further investigation to participate in our study

Regarding (a)
Data verifying the problems of innumeracy and math anxiety abound in the literature, but many science instructors lack the time and/or inclination to keep up on the broader educational literature, and rely on workshops to boil it down to its important points. This has been very successful in the area of learner-centered teaching techniques, and we hope that these workshops will be met with similar enthusiasm by the community.

Regarding (b)
We have already begun compiling our materials and vetting new ones in our own classrooms. These include:
- Daily quantitative brainteasers
- Quantitative supplements to questions in the very popular *Lecture Tutorials in Introductory Astronomy* workbook
- Homework and test questions involving simple arithmetic reasoning
- Labs in which student evaluate the reasonability of numbers presented in popular media
- Labs in which students examine selection effects and how to recognize them in data
- "Real life analogs" to astronomical formulae and graphical relationships
- a variation of the very popular science v. pseudoscience curricula espoused by experienced educators such as Doug Duncan (CU Boulder) with the additional component of how to recognize good mathematical data vs. bad

Regarding (c)
Workshop participants will be asked to participate in the study, and we hope that the workshop will convince them that whether and how numeracy should be emphasized in the science classroom is an open question worth pursuing.

QL Study

Science faculty have been trained to manipulate and interpret numerical data, and quantitative literacy is fundamentally *applied* mathematics, so the sciences are a natural place to begin emphasizing such skills. A majority of college students are required to complete one course in science before graduation in order to fulfill distribution requirements. Data compiled by the American Institute of Physics (2010) reveal that "introductory astronomy enrollments have remained in the 180,000-190,000 range since 2004" (Nicholson and Mulvey, 2010). This figure does not include community colleges, where "an estimated 100,000 students take Astronomy 101 in departments not covered by the AIP survey" (Fraknoi 2001). According to a Bureau of Labor Statistics report entitled "College Enrollment and Work Activity of 2010 High School Graduates", in Fall 2010, 2.2 million people were enrolled in college in the U.S. This means that more than 10% of college students eventually pass through the door of an "Astronomy 101" course in college. This large population is why we feel that introductory astronomy courses for non-science majors are a logical place to begin a study of the efficacy of science courses in improving quantitative literacy in the general college population.

Study Timeline
Fall, 2010 3 Questions, 2 classes (our own)
Spring 2011 22 Questions, 1 class
Fall 2011 2+ (still recruiting) classrooms, Online Interface

Demographics
Class
Major
Gender
First Language
Educated in US?
Math classes completed
Most recent math course
Most recent science course

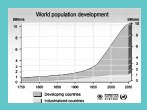
Numerical Skills
Percentages
Fractions
Multiplication
Division
Simple Unit Conversions
Area
Estimation
Error
Graph Reading/Interpretation

Numeracy Opinions
Self-assessed math/science skills
Importance of numerical skills in everyday life
Frequency with which graphs/numerical skills encountered/used in daily life

Sample Questions

1. You begin by measuring out the peanut butter in a 2 cup glass measuring cup like that shown at right (i.e. you fill it to the ¾ cup line). If you are to add the shortening to the same measuring cup on top of the peanut butter, which line should you fill it to?
the 1 cup line
the 1 ¼ cup line
the 1 1/3 cup line
none of the above

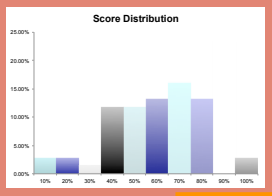
2. You get a letter from your cable company saying that they will be raising your monthly rate by $5. Assuming that the rate does not change again, how much **additional** money will you be paying to the cable company over the course of the next **three** years?
$60
$100
$130
$180



3. In 2050, how many people will be living in industrialized countries?
fewer than 1 in 5
fewer than 1 in 10
more than 1 in 5
about 1 in 6

How confident are you in the answer you just selected for question _?
(a) very confident (b)confident (c) not very confident (d) I guessed

Preliminary Results



Actual Score ~10% lower than Predicted Score
Mean=66%
Standard Deviation = 22%

How to Get Involved

How YOU can help:

Give the survey to your class! We're still recruiting instructors for Fall, 2011 and Spring, 2012!

We'd also love your feedback.
- Do you feel there are any necessary QL skills missing from our list? Which do you feel are the most important?
- We'd love to see how you emphasize quantitative skills in your labs, lectures, homeworks etc and will be happy to keep any materials you provide confidential or to add them to our resource database for the workshop series.
- How do you connect quantiative skills to science, astronomy and real life in your classroom?

Takeaways

- Many Americans leave college with significant lingering deficits in Numerical Skills.
- Women, minorities and the learning disabled are particularly likely to fall into this group.
- Cross-curricular application of numerical skills is likely the only way to convince students of their usefulness
- Introductory science classes for non-majors are for many students their last opportunity to see applied mathematics in context
- Because of its broad appeal and large enrollment numbers, Introductory Astronomy in particular is an important place to emphasize numerical skills
- In many cases these are algebraic skills that students should have learned long ago, however as the last step in their education, we as college educators can't afford to wait for secondary school reform to fix the problem
- YOU are your often students' last chance to appreciate the role of mathematics in science and the importance of mathematical sophistication in their roles as consumers, voters, citizens, parents and in many cases future educators!

[1] Mathematics and Democracy: The Case for Quantitative Literacy, The National Council on Education and the Disciplines (2001)
In particular:
Ewell, Peter, Patricia. "The Emergence of Numeracy".
Ewell, Peter. "Numeracy, Mathematics and General Education"
Kennedy, Dan. "The Empowerful Vanishing Clothes"
Orrill, Robert. "Mathematics, Numeracy and Democracy".
Schoenfeld, Alan. "Reflections on an Impoverished Education"
Quantitative Literacy Design Team. "The Case for Quantitative Literacy".

[2] Quantitative Literacy: Why Numeracy Matters for Schools and Colleges, The National Council on Education and the Disciplines (2003).
In particular:
De Lange, Jan. "Mathematics for Literacy"
Hughes Hallett, Deborah. "The Role of Mathematics Courses in Quantitative Literacy"
Orrill, Robert. "Foreword"
Packer, Arnold. "What Mathematics Should 'Everyone' Know and Be Able to Do?"
Rosen, Linda P. "Quantitative Literacy in the Workplace: Making it a Reality"
Schaeffer, Richard L. "Statistics and Quantitative Literacy"
Wiggins, Grant. "Get Real! Assessing for Quantitative Literacy"

"Highlights from the 2003 International Adult Literacy and Lifeskills Survey". *National Center for Education Statistics* (2005).

"National Adult Literacy Survey and 2003 National Assessment of Adult Literacy." *U.S. Department of Education, Institute of Education Sciences, National Center for Education Statistics*, (1992).

Apter, A.J. et al. 2008. "Linking numeracy and asthma-related quality of life". *Patient Education and Counseling*, 75, 366 (2009).

Ashcraft, M.H. "Math Anxiety: Personal, Educational and Cognitive Consequences". *Current Directions in Psychological Science*, 11, 181 (2002).

Beilock, S.L., Gunderson, E.A., Ramirez, G. and Levine, S.C. "Female teachers' math anxiety affects girls' math achievement". *PNAS*, 107, 1860 (2009).

Betz, N.E. "Prevalence, Distribution and Correlates of Math Anxiety in College Students". *Journal of Counseling Psychology*, 5, 441 (1978).

Betz, N.E. and Hackett, G. "The Relationship of Mathematics Self-Efficacy Expectations to the Selection of Science-Based College Majors". *Journal of Vocational Behavior*, 23, 329 (1983).

Brown, S.M., Culver, J.O., Osann, K.E., MacDonald, D.J., Sand, S., Thornton, A.A., Grant, M., Bowen, D.J., Metcalfe, K.A., Burke, H.B., Robson, M.E., Friedman, S. and Weitzel, J.N. "Health literacy, numeracy and interpretation of graphical breast cancer risk estimates". *Patient Education and Counseling*, 83, 92 (2011).

Chan, L.K.S. and Dally, K. "Learning disabilities and literacy and numeracy development". Australian Journal of Learning Difficulties, 6, 12 (2009).

Charette, M.F. and Meng, R. "The Determinant of Literacy and Numeracy, and the Effect of Literacy and Numeracy on Labor Market Outcomes." *The Canadian Journal of Economics*, 31, 495 (1998).

Couper, M.P. and Singer, E. "The Role of Numeracy in Informed Consent for Surveys". *J Empir Res Hum Res Ethics*, 4, 17 (2009).

Dolber, E.F.C. "It's the Journey." Exploring the Consequences of a Professional Development Workshop for College Astronomy Faculty". (2008) (Doctoral dissertation). Retrieved from ProQuest. (UMI 3336553).

Fraknoi, A. "Enrollments in Astronomy 101 Courses". *The Astronomy Education Review*, 1, 121 (2001).

Henderson, C. " Promoting instructional change in new faculty: An evaluation of the physics and astronomy new faculty workshop". *American Journal of Physics* 76, 179 (2008).

Jackson, C.D. and Leffingwell, R. J. "The Role of Instructors in Creating Math Anxiety in Students from Kindergarten through College". *Mathematics Teacher*, 92, 583 (1999).

Kirsch, I.S. et al. "Adult Literacy in America: A First Look at the Results of the National Adult Literacy Survey". *National Center for Education Statistics* (1993).

Meece, J.L., Wigfield, A. and Eccles, J.S. "Predictors of Math Anxiety and Its Influence on Young Adolescents' Course Enrollment Intentions and Performance in Mathematics". *Journal of Educational Psychology*, 82, 60 (1990).

Nicholson, S. and Mulvey, P. "Astronomy Enrollments and Degrees: Results from the 2008 Survey of Physics and Astronomy Enrollments and Degrees". *American Institute of Physics* (2010).

Ogbu, J.T. "Minority Status and Literacy in Comparative Perspective". *Daedalus*, 119, 141 (1990).

Peters, E., Hibbard, J., Slovic, P. and Dieckmann, N. "Numeracy Skill and the Communication, Comprehension and Use of Risk-Benefit Information". *Health Affairs*, 26, 741 (2007).

Peters, E., Hart, P.S. and Fraenkel, L. "The Influence of Numeracy, Framing and Format of Side Effect Information on Risk Perceptions". *Medical Decision Making* (December, 2010).

Raudenbush, S.W. and Kasim, R.M. "Cognitive Skill and Economic Inequality: Findings from the National Adult Literacy Survey". *Harvard Educational Review*, 68, 33 (2009).

Resnick, H., Viehe, J. and Segal, S. "Is Math Anxiety a Local Phenomenon? A Study of Prevalence and Dimensionality". *Journal of Counseling Psychology*, 29, 39 (1982).

Rousselle, L. and Noel, M.P. "Basic numerical skills in children with mathematics learning disabilities: A comparison of symbolic vs non-symbolic number magnitude processing". *Cognition*, 102, 361 (2007).

Schwartz, L.M., Woloshin, S., Black, W.C. and Welch, H.G. "The Role of Numeracy in Understanding the Benefit of Screening Mammography". *Ann Intern Med*, 127, 966 (1997).

Steen, L.A. "Numeracy: The New Literacy for a Data-Drenched Society". *Educational Leadership*, 57, 8 (1999).

Wigfield, A. and Meece, J.L. "Math Anxiety in Elementary and Secondary School Students". *Journal of Educational Psychology*, 80, 210 (1988).