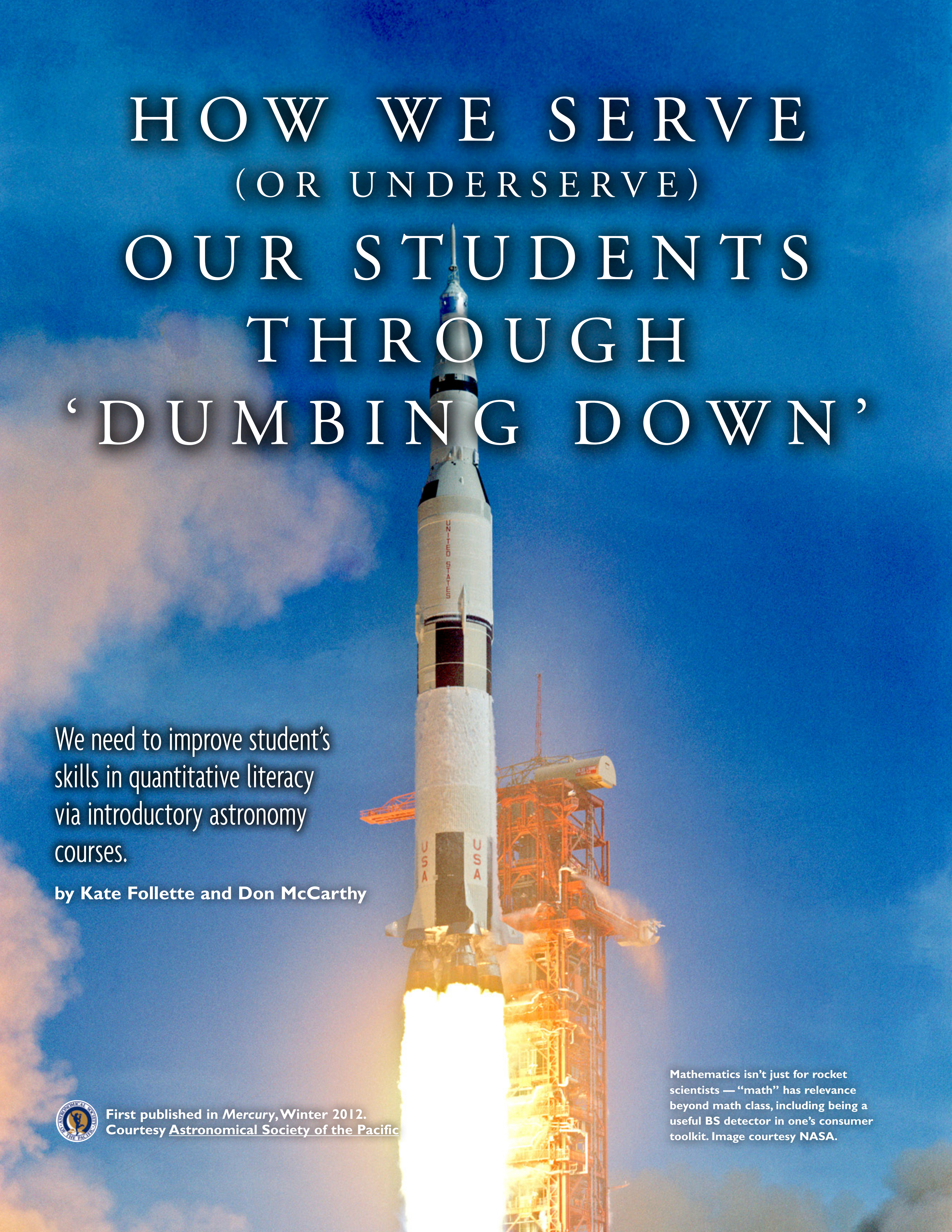

HOW WE SERVE (OR UNDERSERVE) OUR STUDENTS THROUGH 'DUMBING DOWN'

We need to improve student's skills in quantitative literacy via introductory astronomy courses.

by Kate Follette and Don McCarthy

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Courtesy Astronomical Society of the Pacific

Mathematics isn't just for rocket scientists — "math" has relevance beyond math class, including being a useful BS detector in one's consumer toolkit. Image courtesy NASA.

“Math is only useful to pass a test in math class,” said the college honors student with authority. As a lover of all things mathematical, I was initially shocked, but it did get me thinking: How valuable is mathematics to the average citizen?

Am I just biased in its favor because, as a scientist, I use it in my day job? By emphasizing basic numerical skills in my introductory astronomy curriculum, am I subjecting my students to unnecessary angst and agony? If I avoid teaching such skills in my course, am I contributing to the dumbing down of a new generation? My students are definitely vocal with their complaints about it. Do they have a valid point? Could I teach numerical thinking in a more exciting way that inspires my students to improve their skills?

Dumbing Down Science to Avoid Math?

“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….”

— From an application to Astronomy Camp by a 13-year-old girl.

Kate's Story: Awash in Numbers

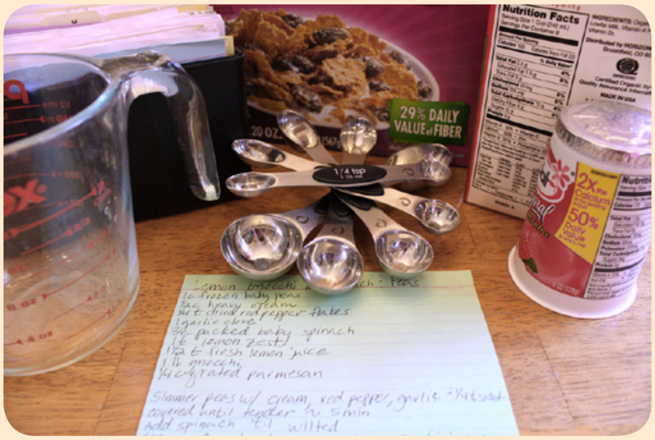
They say that you should start with what you know, so I decide to begin by considering an average day in my own life. I get up and, because I’m on a diet and am naturally compulsive, I measure out my breakfast. One cup of my cereal has 130 calories. I look in my kitchen cabinet, but my one-cup measure is missing. A quick glance in the dishwasher confirms that I used it last night to measure out yogurt for a smoothie. It’s Monday, and I’m not a morning person — the odds that I’m going to put in the effort to wash out the crusty yogurt are approximately 1:1,000,000. So I take the ½-cup measuring cup and fill it twice. But I want only ¼ cup of milk, so I fill the cup halfway with milk and dump it into the bowl.

The nutrition information on the back of my juice container says there are 100 calories per eight ounces. I think for a second and then remember that there are eight fluid ounces in a cup, so I rinse my ½-cup out and fill it twice more with juice.

After consuming my breakfast, I go upstairs to shower with my generic bath products, which I purchased after considering their price per ounce relative to their name brand counterparts. As a graduate student, sometimes every cent counts!

My husband and I get into our Nissan Leaf to carpool to work. Let’s not get into the irony of saving 10 cents on shampoo and then going out and buying a new car. For one thing, my husband is an alternative energy geek, and he really wanted it. Besides, my father drilled into me (from an early age) the rule of putting one-third of my income per paycheck into savings, so we were able to afford it without taking out a loan. With an average interest rate of more than 6% for auto loans and a term of five years, this saved us almost $5,000 in the long run.

On the ride in, we watch the battery charge slowly drop and also keep an eye on the mi/kWh meter. I maintain that the kilowatt-hour is the silliest unit ever invented, but luckily it also appears on my electric bill so I remember that it’s a unit of energy. The car tells me I am getting 4.6 mi/kWh on average. I already know that this is better that the average of 4.3 when my husband drives, but how does it compare to a non-electric car?



Kate Follette

Since receiving a long and passionate argument from my husband on the virtue of maintaining a gas log in my other car, I know very well that it gets about 27 miles per gallon (mpg) in the city and 31 mpg on the freeway. I also know that I pay between $3.50 and $4.00 per gallon for gas to fill it up. I don’t want to think too hard about the math, so let’s say it gets 28 mpg on average. I like this because I know it’s divisible by seven, and $7 is twice $3.50. This choice has the added advantage that $3.50 per gallon is on the lower end of the price of gasoline these days, so I don’t seem to be skewing the numbers in favor of the electric car.

Using these numbers, I can say that I get approximately 8 miles for every dollar I spend on gasoline, or about 12 cents per mile. I don’t remember what we’re currently paying for electricity, but my husband tells me that our “blended rate,” which includes all of the fees and fixed costs, is around $0.10/kWh. This means that our 4.3-4.6 miles/kWh translates to less than 3 cents per mile! That’s more than four times better than gasoline. Between this and the reduced emissions, maybe we can

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feel both conscientious and consumer savvy about the purchase after all!

So I haven't even made it an hour into my day, and already I've dealt with fractions, percentages, unit conversions, division, and estimation. Let's ignore anything that I do at work by assuming that, as a scientist, I lead a more quantitatively saturated work life than the average Jane. But what if we stop for groceries on the way home? The grocery store is inundated with numbers! Prices per pound, 10 kiwis for $3, 10% off of wine if I buy 12…and on it goes. From grocery to department store, from monthly bills to tax deductions — far from encountering math only in the classroom, the average person can't escape math on a daily basis even if they try!

My next thought is that as a scientist, I have been trained to manipulate numbers — to estimate, read graphs, and think about errors and mathematical methodology. Putting aside the everyday calculations I've just described, the argument for the importance of quantitative reasoning in the everyday life of the American citizen could be taken even further.

What do my students think when they're confronted with graphs and statistics in the media, for example? Probably not much besides what they are told they should conclude from it. In my experience, the mere fact that data or numbers are associated with something seems to lend them a sense of undue credibility in their eyes.

If I don't teach my students to be mathematically savvy in "their terminal science class in life" (to quote the Center for Astronomy Education's Ed Prather), where else will they see applied mathematics and learn to appreciate its usefulness as a BS detector and weapon in their consumer toolkit? It's easy to point the finger at any and every step in their prior education — to say that it's not my job to remediate arithmetic skills that they should have learned in primary school and analytical skills that they should have learned in high school science. But when it comes right down to it, I'm the end of the line in their science and mathematics education.

Can Introductory Astronomy Help Turn the Tide?

Kate's story reflects a problem faced by many, if not most, introductory college science instructors. Resistance to, fear of, and ineptitude with numerical manipulation is rampant, particularly among those who have chosen college majors outside the STEM fields. It's also often accompanied by a willingness to take numerical and graphical representations at face value, without applying the critical thinking skills that Carl Sagan so aptly termed "The Fine Art of Baloney Detection."

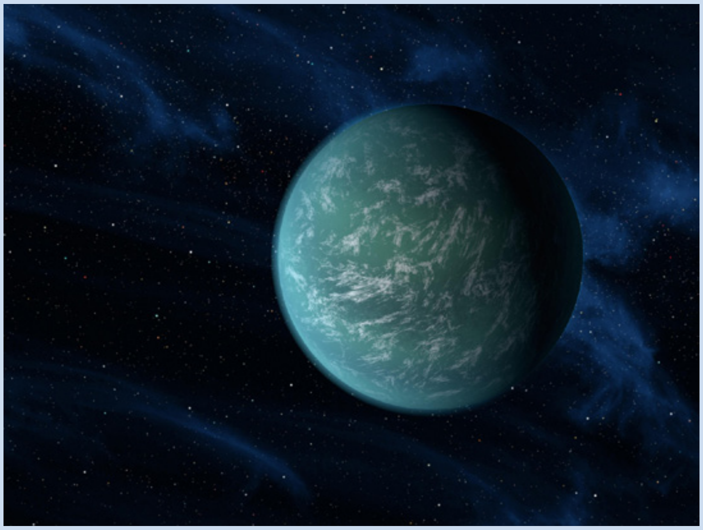
Is it possible for us, as introductory astronomy instructors, to reverse the trends of math anxiety, credulousness, and quantitative illiteracy? We think it can be done, and we believe we have to try. As the quantitatively illiterate continue to pass into the realm of the college educated, aren't we at least partially to blame?

This burden is not easy to bear, so we have reconsidered the goals and content of our courses. Of course we want our students to know about the reason for the seasons, the evidence for the existence of dark matter, and the excitement surrounding the emerging field of exoplanet astronomy. But if we could just make them a little more comfortable with numbers, and a little savvier about graphs and statistics, we would make a bigger difference in their lives.

We believe astronomy can be taught using a common sense, everyday language that promotes numerical thinking, deepens students' understanding of basic astronomical concepts, and changes their attitudes and abilities for using numbers in their major fields of study. In our experience this language should emphasize elementary arithmetic and proportional thinking more than detailed calculations; in other words ratios, fractions, percentages, estimation, multiplication, and so on. This language should extend throughout every facet of the course to demonstrate that "math" has relevance beyond math class.

Common Mathematical Misconceptions

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



NASA Ames / JPL-Caltech

NASA's Kepler mission has confirmed its first planet in the habitable zone — Kepler-22b. The planet is about 2.4 times the radius of Earth, and its mass is 12.9 times that of Earth. The force of gravity on the surface of a planet is proportional to the planet's mass, and inversely proportional to the radius of the planet squared. What would be the weight of a 100-pound human standing on the surface of Kepler-22b?

Our Quantitative Literacy Study

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.

We have begun a study to determine whether the inclusion of numerical skills into the curricula of introductory astronomy courses for non-majors improves students' comfort with, and ability to manipulate and reason with, numbers (their quantitative literacy). Essential skills identified in the literature and in the National Assessment of Adult Literacy include graph reading, proportionality, percentages, probability, and number sense. The study uses an online interface to assess students' attitudes and abilities at the start and end of a semester of introductory science.

We hope that the results will reveal whether introductory science courses for non-majors are a good forum for developing numerical skills and improving attitudes towards mathematics. We also intend to use the results as a basis for a workshop series we're developing for science faculty, with the dual goals of raising awareness of the problem of quantitative illiteracy and sharing tips, tricks, and curricular materials that we have developed to foster it.

Results from the literature suggest that neither math anxiety nor innumeracy is correlated with math ability (Ashcraft, 2002). Both are strongly correlated, however, with math avoidance. This means that both innumeracy and math anxiety are significant sources of leaks in the STEM pipeline. In fact, the relationship between low self-efficacy expectations in mathematics and a tendency to avoid science-based college majors was revealed more than 25 years ago (Betz, 1983), yet very few studies have since investigated how to alleviate it, and none through the vehicle of college-level introductory science.

We believe that our study is an important first step in revealing whether introductory science courses for non-majors can be used to reverse negative attitudes towards mathematics, alleviate math anxiety, and develop the numerical skills that are essential for our students' success in life.

Statistics from the National Adult Literacy Survey (NALS)

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."

Key results include:

- More than 20% of American adults performed at the lowest level of proficiency with another 25% at the next level.
- Quantitative proficiency of younger adults was lower than that of older adults, suggesting that general proficiency is declining with time.
- Individuals with the highest numerical proficiencies were more likely to be employed and to earn two to three times higher salaries.
- Non-white adults were more likely to be in the lower two levels.
- The proficiencies of men were somewhat higher than those of women.

Also, about 15% of our non-major students (according to the initial survey responses) are pre-service teachers. Since many students learn 'math anxiety' from their teachers, leaving our future teachers with an improved attitude toward mathematics is a very important step towards mitigating math anxiety and improving quantitative literacy in future generations.

— K. F. & D. M.

Join Us!

If the results of our quantitative literacy study are favorable, we plan to develop workshops to teach educators and scientists how to incorporate numerical thinking more effectively, and with less pain, in their classes. These classes need not be limited to the teaching of astronomy and science but also can extend across the school curriculum as well as to informal venues. Through improvements in the conduct of science classes (i.e. language), classroom activities, homework, and lab exercises, students will gain a deeper understanding of the scientific process and can realize the value of mastering numerical skills for their own careers.

To participate in the study, contribute workshop materials or for more information, please contact Kate Follette and/or Don McCarthy.

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