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BY SIMON BOXALL

A Sum of All Knowledge, or A Knowledge of All Sums?

A while ago, I had coffee with an old colleague who now teaches oceanography in college to 18-year-olds. She told me she was discussing the basics of navigation when a student put his hand up and asked, "excuse me, but what is the meaning of sin?" Somewhat perplexed as to why a student should be bringing philosophy and ethics into science at such an early stage in his career, she asked him to clarify the question. "Well, you've written sin and cos all over the board—what does that mean?" In a chuckle of disbelief, she asked, "Does anyone else not know what sin and cos are?" Half the members of the class raised their hands.

This story is, perhaps, an extreme example of the modern-day issue of students in science not being as mathematically literate as they once were. But, how big is the problem, where does it stem from, and how do we solve it? Although I cannot provide a solution, even in an esteemed journal such as this one, I have a fair amount of experience with the problem, having taught physical oceanography to first-year university students for longer than I care to remember. In the 1980s, I went slowly through derivations involving complex numbers or double integrals, but didn't think twice about trigonometry or algebra—these skills were a given. Now, they are a starting point for some students.

Mathematics is a strange subject, no doubt about it. Solving equations is a skill that, if not used regularly, is easily forgotten. Mathematics is the one subject at university where faculties strongly discourage students taking a gap year, as they will lose the edge. I can no longer sprint through matrix transformations, but in my student days I could solve a few before breakfast. But, an ability to juggle numbers and equations, and to quantify what we do, is fundamental to all disciplines of oceanography. At Southampton, we even insist that our prospective marine biologists take mathematics to a higher level at high school or college.

So, what has changed in the education system to yield such a diversity of mathematical abilities? The exam system at school level has become far more modular—it is possible in the UK to take math to a high level, yet avoid any classes in calculus! In addition, students no longer do "back-of-the-envelope" calculations, which are great for the mind and for checking final results. The envelope has been replaced by the ubiquitous computer to take raw data and convert them into statistical variables, graphs, Reynold's numbers, and so on. This dependency on modern technology not only removes mental ability, but also reasoning. I get students who, given a water column density profile, will calculate an average density ten times that of any in the range within the profile. They will then wonder how I know they are wrong so quickly.

The problem needs solutions at the university level. Compulsory modules in mathematics of one form or another have appeared in the past 10 or 20 years in most oceanography courses worldwide. It is difficult to find a "one-course-fits-all solution," as the more numerate students rapidly tire if they are not being stretched. Our mathematics faculty members provide a series of courses for

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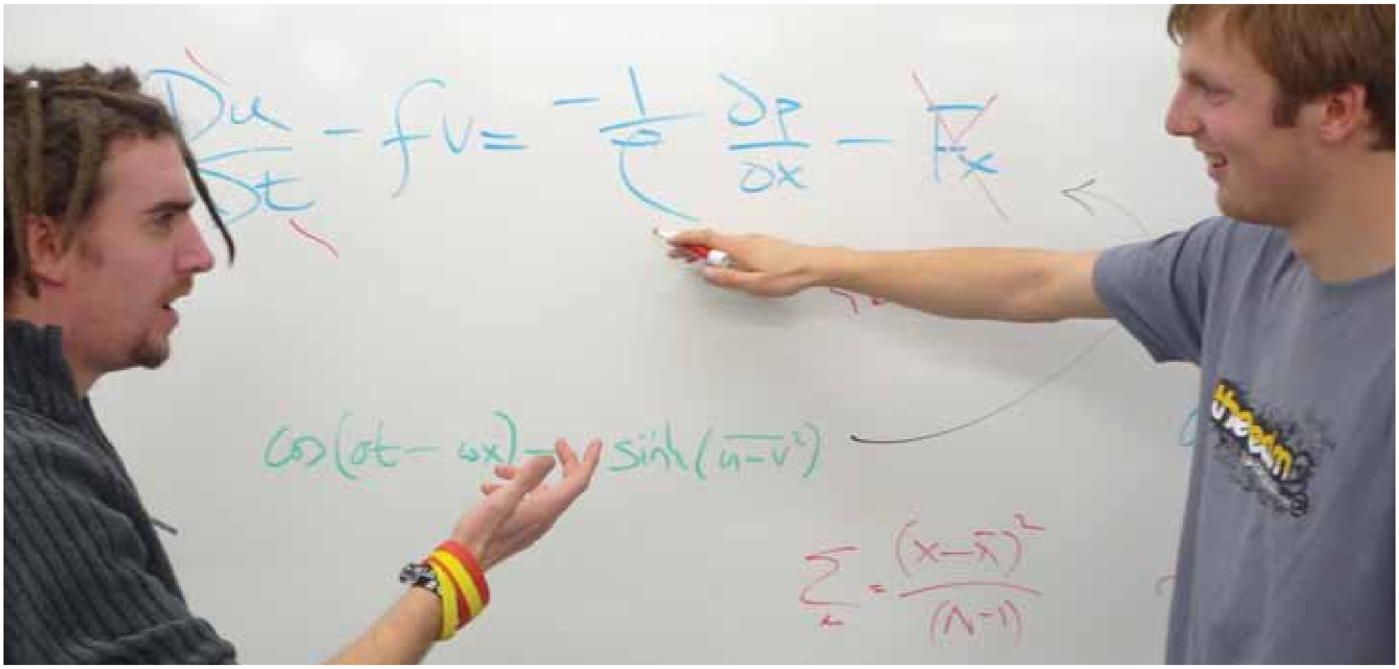

different abilities, which does go some way to solving the issue. The problem is that math taught by mathematicians will go into more depth than is needed and often goes way off track. They also fail to understand the struggles mere mortals have with the basics.

I am convinced that some of the lack of confidence in using equations comes down to language. Look, for example, at the different notation used in calculus by mathematicians, physicists, and oceanographers. I can tell a colleague's background in science just by looking at how they write their equations. We are all using the same principles but different languages—it is like some are speaking French while others speak German. Once you appreciate that distinction, then the translation between notations used is easy, but it takes experience and confidence.

Even at a simple level, students can be thrown. Change water depth from *h* one week to *d* the following and the sound of 10 brains popping will be heard in the audience. We use symbols to represent physical things, but the symbols used do not matter as long as you define them—they are just symbols. As an undergraduate, I missed the lecture where the term σ (sigma) was used as shorthand for density. It was never explained again, and I am ashamed to admit it was a year before I realized that it was not some complex derivative of the parameter.

Mathematics needs to be taught to oceanographers by oceanographers, focusing on the essentials. At Southampton, we are now introducing these classes. Students do not need to derive equations from first principles (unless, of course, a student is going on to advanced physical oceanography), nor do they need to know the 20-page origin of every statistical technique known to humankind. They do have to manipulate equations and understand what they represent—and when to use them! Give an untrained student a statistics package, and the person will prove that cod stocks in the North Atlantic are directly related to the occurrence of toxic algal blooms off Bengal, divided by average shoe size.

One of the key starting points is units! Ask a first-year student for the units for something as basic as density, and a number of them will struggle. Offer them an equation for a parameter and ask them to calculate the units of that parameter, and even more will fail—especially if it is a nondimensional number. I am forever forgetting the details of the obscure equations, but can always check by ensuring that the units add up—that old back-of-the-envelope approach. The units problem is not helped by our profession—take light intensity as a good example. As a physical oceanographer, I use W/m^2—obvious to me. One of my mathematical colleagues uses cd (candela)—OK, I would just add per steradian to my W/m^2, but it's then the same physical thing. Our biologists often use microeinsteins/m^2/s while chemists use mol/m^2/s, and I won't even start at foot candles (and before you all write and complain, I know there is a wavelength dependency as well). Students do get confused and we often have a

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debate at faculty level about standardizing the units and symbols we use. I am against that, as the journals and textbooks are also all different, and when students graduate and move on they will encounter this *biodiversity* of units and equations. It is far more important that they learn and appreciate the differences, or, more correctly, the similarities.

Next, we have the basic mathematical functions from trigonometry to exponentials and logarithms. All students will have covered these subjects in the past, and, along with the other key skill of manipulating equations (algebra), it is a question of practice and familiarity. Not only do these skills need tackling within the basic mathematical courses we run, but they need reinforcing in the other oceanography and marine biology modules. Making students remanipulate equations to arrive at the answer in a laboratory practical, or making them sort out their ship-course tracks when working at sea without the navigation computer, all help. It sounds almost like kindergarten, but we all need to exercise the sums bits of our brains.

The more complex mathematical and statistical issues are about understanding rather than derivation, unless you are aiming at that career in numerical modeling or physical oceanography. Differentiation and integration can be taught at a high level, with students being able to solve complex differential equations. But, the majority of students only need to understand what a differential or an integral represents and how to apply it in real life. We could, for example, look at the intricate issue of the derivation of $\Delta u/\Delta t$ in the basic equations of motion, complete with their partial derivatives, and show how we can solve the full equation of motion (or, perhaps more correctly, not fully solve them!). Or, we could explain that it represents the rate of change of flow with time and includes terms that look at the time rate of change as well as spatial rates of change. For a single location, given some current meter data, a student can even calculate $\delta u/\delta t$ without being a whiz at calculus, but don't forget those units.

The level of mathematics inherent in students of oceanography and marine biology is different today than what it once was. There are more pressures at school to take classes in a diversity of subjects, and even oceanography has more material to cover today than it ever has done in the past. Students have less time to play with numbers and equations to build up confidence and experience. It now falls to universities to fill in the gaps and to ensure math is on the transferable skills tick list. We need to focus on what is needed and not rely on textbooks or faculties of mathematics and statistics to do that—the learning curve is too steep and the material unfocused. More primers and courses are now being produced and delivered by marine scientists for marine scientists, and many are now available online. These resources will, I hope, prevent our subject from going into numerate oblivion in 23.56 years, though that is only a back-of-the-envelope calculation.