A page-long section of *About Time* refers to the public outrage against Hawking's *A Brief History of Time* by the British "chattering classes" – the arts and literary fraternity that tend to dominate intellectual life in the UK. This hints at the bitterness that led to Davies' move to Australia. As Davies later explained to me: "There are very deep-seated anti-science prejudices at work in the UK, not only connected with religion, but the arts mafia, the class system and other peculiarly British hang-ups. It is the principal reason that I decided to leave Britain. Australia is a far more tolerant country, and its literary intellectuals do not try to rubbish science all the time, as in the UK." In my opinion, this division illustrates the deep need for books such as Davies' to explain the scientific enterprise to those who are mystified by it.

As a scientist who is used to refereeing papers as critically as possible, I could not resist looking for possible errors in *About Time*. All I found were a few minor ones, such as saying that if the Earth's motion were resisted by the ether, it would "slow up and fall into the Sun". (It would in fact lose energy and angular momentum, fall inward, and speed up, an effect related to the negative specific heat of gravitational systems.)

Another slightly more misleading error is on p175, where it is claimed that in an experiment at the University of Rochester (unfortunately with the diagram on p174 printed upside-down) an interference pattern of "signal" photons was changed by altering beams of "idler" photons "even though the idler and signal photons remained physically well separated at all times". However, in the original reference it is clear that the idler beams entered the crystal, where one of the signal photons was produced, and it was explicitly stated that the idler beam "has induced coherence between [the signal beams]". If altering the idler beams indeed could change the signal photons without there being a physical connection, one could in principle use this change to send signals between regions not physically connected, which is believed to be impossible.

About Time ends with a chapter starting with a delightful remark from David Deutsch that "the history of science is the story of physics hijacking topics from philosophy". Davies adds, "The subject of consciousness may be the next on the list," which made me feel like a hijacker for some of my own recent speculations.

Then Davies lists 12 outstanding puzzles of time that remain: tachyons, black holes, time travel, quantum mechanics, quantum gravity, the origin of time, the age of the universe, the cosmological constant (which he had earlier bet would eventually be shown to be non-zero: "It will surely represent the supreme irony: from a study of Einstein rings, which Einstein himself never believed were observable, astronomers would have shown that Einstein's greatest mistake was in fact his greatest triumph".), limits to general relativity, the arrow of time, *T*-violation and the psychological flow of time.

On the last of these, Davies writes: "In my opinion, the greatest outstanding riddle concerns the glaring mismatch between physical time and subjective, or psychological, time." I agree. Physics still has a lot to learn as it hijacks more and more time from philosophy.

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Michael Berry

Numbers, words and things

Nature's Numbers: Discovering Order and Pattern in the Universe
Ian Stewart 1995 Weidenfeld & Nicholson 164pp £9.99hb

IAN Stewart is one of very few people who can explain mathematics to the non-specialist, even non-numerate, public. For many years his cheerful accounts of Fermat's last theorem, the packing of spheres, and so on, have kept readers of newspapers and popular science magazines informed of discoveries at the leading edge of pure mathematics. Here he tackles the more difficult task of describing how mathematics has been applied to the world – and in particular science – and the different ways that it is currently being used.

That the task is indeed more difficult will be familiar to many readers of *Physics World*: university students can grasp the technicalities of an experiment, and follow the details of a mathematical derivation, but get stuck where the two meet.

This reflects tricky philosophical questions. What is the reason for what Wigner called "the unreasonable effectiveness of mathematics in the natural sciences"? Do mathematical truths exist in the same sense as physical objects? Many authors have discussed such questions (a good recent popular account is John Barrow's *Pi in the Sky*), but Stewart does not address them directly. Instead he presents a series of case studies, each involving a key mathematical idea. In this he is following the admirable strategy attributed to the numerical analyst Beresford Parlett, who said: "Only wimps specialize in the general case; real scientists pursue examples."

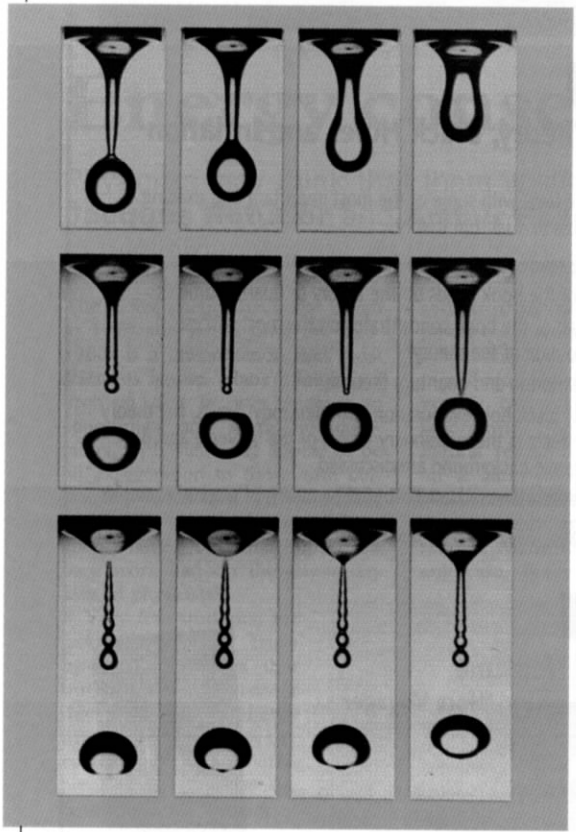
There are, however, some well chosen generalities about mathematics itself. The idea of proof is illustrated with the SHIP–DOCK theorem. The idea is to show that the word "SHIP" can be transformed to "DOCK" through a series of valid English four-letter words by changing only one letter at a time. The "Aha! Insight!" moment, when the central point is grasped, is the realization that at least one intermediate word must contain two vowels.

The distinction is also made between symbols and what they represent ("Not notations but notions", as Gauss said). This contrasts slightly with what Stewart calls "thingification" – the transmutation in mathematicians' minds of processes into objects. This can happen for example with operators, such as those representing motions of the plane or space, or the taking of square roots. He makes a good analogy with drugs and theft: "one genuine thing and one thingified thing, both treated as if they were on exactly the same level".

The first case study is a conventional subject: mechanics. Stewart emphasizes two aspects. Certain invariants underlie motion (hence the title: "The constants of change"). For a simple falling body, acceleration is constant; in general, it is the form of the equation of motion that does not change as the body moves. What it means to "solve" a dynamical equation has also altered over the centuries. As Stewart explains: "First that word meant 'find a formula'. Then its meaning changed to 'find approximate numbers'. Finally, it has in effect become 'tell me what the solutions look like.'"

Of course, this apparent retreat is really an advance, caused by the recognition of dynamical chaos, where "the crevasse between laws and behaviour might not always be bridgeable". Chaos is discussed later in the book in detail. The plane depicting changing populations of pigs and truffles in a "predator and prey" scenario illustrates the phase space of a dynamical system. The increasingly disordered sound patterns of a dripping tap, as the flow rate increases, illustrate Feigenbaum's universal ratio governing sequential bifurcations – "one of nature's numbers, indeed".

Another theme is the interplay between symmetry and symmetry-breaking. This is well explained in terms of the failure of


Chaos on tap – time lapse photographs of the formation of a drop. Courtesy of Sidney Nagel and X D Shi, University of Chicago

Curie's principle that "effects are as symmetrical as their causes", and illustrated with spontaneously time- and space-varying chemical reactions, and the transverse and longitudinal waves on wind-blown sand (although it is not made clear what determines which kind of wave). I was sorry not to see phase transitions here, as it is helpful to point out that both melting and freezing are symmetry-breaking. Melting breaks the lattice translational symmetry of the solid, and freezing breaks the time-averaged continuous translational symmetry of the liquid.

As well as telling us how simple causes generate complicated motion (because of chaos), Stewart emphasizes the opposite: how "nature's simplicities" can emerge from very complicated mechanisms. I particularly liked two examples from current applied mathematics. In the chaotically dripping tap, the apparently simple detachment of an individual drop is revealed (by both experiment and fluid mechanical theory) to be an astonishingly intricate process, involving a hierarchy of tiny threads breaking into smaller drops. Second, a new solution has been proposed for the old problem of why the spiral arrangement of flower petals involves sequences of Fibonacci numbers (where each number is the sum of the preceding two). Simple dynamics ensures that the migrating primordia (that will become the petals) separate along directions differing by the golden fraction of a circle (close to 137.5°), and ratios of Fibonacci numbers are successive approximations to this ratio.

To his credit, Stewart resists any temptation to muddy his exposition by dwelling on the sociology of mathematics. However, it is good that he finds space to stress, again with good examples, the essential dependence of our civilization on mathematics, and to attack the current fashion for "focusing on the applications as a goal and ignoring 'curiosity-driven research' ". (What an offensive term that is.)

I suspect that Ian Stewart has had this book in him for a long time. It is very well written – occasionally with passion and sometimes beautifully, as in the prologue about the revolution caused by simulating dynamical trajectories as flow lines. It would be an ideal Christmas gift for someone who wants – or needs – to know how mathematicians think.

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