BOOKS: NEUROSCIENCE

The Brain's Number-Crunching Power

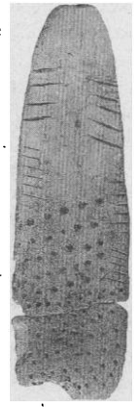
Marc Hauser

Imagine opening a tabloid paper to read—next to headlines about Liz Taylor's nth marriage and a recent martian invasion—that humans are born with the capacity to do simple math. Surprise would certainly be a justified response. After all, infants can't see all that well, can't walk, can't understand jokes, and have no sense of self. But recent research on infants and studies of many nonhuman animal species suggest that basic numerical abilities are part of the brain's standard equipment. In *What Counts*, neuropsychologist Brian Butterworth argues that humans, and many other animals, are endowed with an innately specified number module, a dedicated part of the brain that computes simple numerosities. Over human evolution, this module has developed into a system capable of using symbols (including lines in the sand, body parts, written tokens, and, of course, words for numbers) in functions of long division, trigonometry, and calculus.

Butterworth's book follows several others, also written for lay audiences, that make the case for domain-specific systems of knowledge: Pinker's *The Language Instinct*, Hoffman's *Visual Intelligence*, Baron-Cohen's *Mindblindness*, and Dehaene's *The Number Sense*. These authors draw upon a rich body of evidence from evolutionary biology, neurobiology, cognitive science, developmental psychology, and linguistics to argue that the mind represents a suite of domain-specific systems or modules, each designed by natural selection to serve a particular function. Their argument comprises four crucial steps, illustrated here in the domain of numbers: First, accounting for the acquisition and subsequent mastery of a number skill requires that there be certain kinds of numerical representation that can be operated upon. Second, the genetically specified structure of the mind imposes constraints on the kinds of numerical representations that an individual can have. Third, to acquire numerical skills, the individual must possess a knowledge acquisition device that is dedicated to the number domain. Fourth, the innately encoded constraints that operate during the process of acquiring number skills are part of the brain's standard equipment. *What Counts* is an attempt to flesh out this argument for the domain of number, as Chomskyan linguists have attempted for the domain of language.

What Counts
How Every Brain Is Hardwired for Math
by Brian Butterworth
Free Press, New York, 1999. 432 pp. $26. ISBN 0-684-85417-1. (*1*)

Relative to other domains of knowledge such as language and mental state attribution ("theory of mind"), research on number provides several advantages, on which Butterworth capitalizes. For example, there is no fossil evidence for either language or mental state attribution, whereas there are now several archaeological findings that suggest when our hominid ancestors started symbolic enumeration. Hominids were marking bones and making marks on cave walls 30,000 years ago. Although no one knows why these marks were made, they are clearly nonrandom indications of tallying systems; some have argued that they may have been invented to track lunar or menstrual cycles. In addition to the fossil record, we also have considerable evidence that many animal species are capable of spontaneous (that is, in the absence of training) number discrimination; with training, many can even learn the meaning of our Arabic numeral system. In striking contrast, there is no evidence that animals spontaneously generate a language system like ours, nor do they attribute mental states to others. From a comparative perspective, therefore, we can tell a better evolutionary story about number than we can about language, and Butterworth builds a solid case for the claim that the number module is evolutionarily ancient.



Signs of notation. The groups of marks on the 30,000-year-old Lartet Bone (from southwest France) appear to have been made in different ways and with separate tools.

Butterworth's innate number module consists of a simple, domain-specific mechanism for quantifying small numerosities: subitization. This is a low-level, pre-attentive mechanism for assessing the number of objects in a visual array when the total number is less than five. If one to four dots are briefly flashed onto a computer monitor, we can state the number of dots without counting. Evidence that we are subitizing comes from the very fast speed with which we enumerate numbers one through four; we are considerably slower for numbers greater than four. Butterworth supports his claim that subitization is the key mechanism by showing that infants and animals can spontaneously compute small numerosities (up to about four). To exceed this limit, so the argument goes, individuals require an education—for infants, a good teacher, and for animals, a good trainer.

Butterworth also appeals to some elegant data from brain-damaged patients with acalculia and to children with developmental dyscalculia. Both conditions represent cases of apparently selective damage to the number system, with the sparing of all other knowledge domains. For example, an acalculic patient shown three dots on a monitor was forced to count them, rather than subitize; when asked the number of arms on a crucifix, the patient needed the experimenter to stand up and hold out her arms in order to complete the task. Similarly, a child with developmental dyscalculia took longer to give the correct number for two dots than for one dot, and longer for three dots than for two; normal children subitize and thus require the same amount of time for assessing one to four dots. Butterworth's tour through animals, infants, and patients with brain damage or developmental disorders is both fascinating and insightful.

Although I am generally sympathetic to Butterworth's overall argument, a more careful scrutiny of the literature weakens his case. Subitization is clearly an important mechanism, but it cannot be the only one underlying the number module. Many of the studies reviewed by Butterworth require the subject to keep in mind objects that disappear; because the objects are no longer in view, subitization—which takes as input the visual array of objects—cannot operate. Other studies show that subjects can greatly exceed the limits of subitization with visual stimuli, and can compute numerosities for nonvisual stimuli such as jumping puppets and acoustic signals.

For example, Brannon and Terrace's (*2*) work shows that after rhesus monkeys learned to order exemplars of the numerosities one to four, they spontaneously ordered novel exemplars of five to nine. In contrast to many other studies of numerosity in animals, this research explicitly controlled for such factors as size, shape, color, and complexity of the objects—leaving number as the only criterion for ordering. Similarly, Xu and Spelke (*3*) recently demonstrated that infants can discriminate stimuli of 8 versus 16 dots. Together, these studies show

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CREDIT: ADAPTED FOR *WHAT COUNTS* FROM A. MARSHACK, *THE ROOTS OF CIVILIZATION*, 2ND ED. (MOYER BELL, LONDON, 1991).

that subitization is an insufficient mechanism to explain the spontaneous, innate number capacities of animals and infants. It is therefore likely that several mechanisms are crucially involved in number representation during both ontogeny and evolution.

As with all claims for domain-specificity, much hinges upon selective deficits and, especially, cases of double dissociation. Some of Butterworth's cases of acalculia and developmental dyscalculia are clearly not restricted to the number domain. (Charles, for example, a developmental dyscalculic who lacks the capacity to subitize, is also dyslexic.) Evidence that there are deficits outside the domain of number diminishes the strength of Butterworth's claim for domain-specificity or modularity.

The great British philosopher Bertrand Russell stated that "It must have required many ages to discover that a brace of pheasants and a couple of days were both instances of the number two." Actually, it didn't. Romping through the world of animals and humans (young and old, normal and abnormal, living and fossilized), Butterworth's *What Counts* shows why.

References and Notes

1. Released in the United Kingdom as *The Mathematical Brain* (Macmillan, London, 1999).
2. E. M. Brannon and H. S. Terrace, *Science* **282**, 746 (1998).
3. F. Xu and E. S. Spelke, *Cognition* **73**, B1 (1999).

BOOKS: EVOLUTION

Lingua Franca

Fintan R. Steele

"Come, let us go down, and there confound their language, that they may not understand one another's speech."
Genesis 11:7

Scientific dismay over recent gains made by "creation science" can be traced to a lack of education: not so much on the part of the creationists, or even the general population, but our own. Steeped in the methods of science, few of us can articulate (much less defend) the philosophical principles that guide our endeavors. In *Tower of Babel: The Evidence against the New Creationism*, philosopher of science Robert T. Pennock reveals our blind spot to be the hole through which the truck of creationism now careens.

Many scientists dismiss the problem by claiming that science and religion speak different languages, which makes their encounters as futile as communication among the citizens of Babel ineffectually urging one another to flee the falling bricks of their tower. Pennock acknowledges this unbridgeable linguistic gap and moves beyond it, proposing to renew the discussion between the combatants in the lingua franca of philosophy. His goal, which he largely attains, is to provide a common language with which to consider the relative explanatory and scientific strengths of evolution and creationism.

Tower of Babel
The Evidence against the New Creationism
by Robert T. Pennock
MIT Press, Cambridge, MA, 1999. 451 pp. $35. ISBN 0-262-16180-X.

Unlike some scientists, Pennock takes the creationist argument seriously—"not just because it is mistaken, but because it is mistaken in a way that's dangerous." Central to his book are the "new" creationists, new in the sense that, having learned from their recent defeats in the U.S. courts, they have retooled their arguments to omit any specific reference to Christianity or even a personal god. Pennock is at his best in analyzing and refuting their argument that creationism is simply another theory like evolution, one ignored by scientists who fear losing their influence in the modern world. He points out that the new creationist approach is one of attacking scientific method and conclusions without offering anything substantial (except for revelation or the old argument-from-design) in its place. He also intimates that the "theology" of the new creationists is almost as embarrassing as that of scientists who have lately chosen to dabble in a field that requires as much intellectual rigor as their own disciplines.

Pennock's discussion of the evidence supporting evolution is also thorough and well articulated, though perhaps of less interest to scientists. Less persuasive is the parallel Pennock draws between the evolution of life and the evolution of language, which is echoed in the book's title. Although this comparison provides an effective argument against creationism at one level (the intellectual emptiness of biblical literalism), it fails to address the real fears of the creationists. As Pennock himself admits: "The critical issue for the creationist is not really about the truth or falsity of evolution as a descriptive and explanatory scientific theory, or even about the validity of 'creation-science' as a scientific alternative, but rather about their relative viability and worth as value-grounding creation stories."

In other words, the fear driving the creationist agenda is that if evolution holds sway, any meaning to life, and with it the basis for morality, will fall as surely as the Tower of Babel. This fear cannot be lightly dismissed, though some of the excesses to which creationists go in articulating this fear are surprising. (I was particularly amused to learn that homosexuality is considered by most creationists to be a direct evil arising from the acceptance of evolution.) But as Pennock rightly notes, this either-or dilemma (creation equals God versus evolution equals godlessness) is posed by the creationists themselves to win the support of a public untrained in either science or theology. He submits, as have many others, that evolution does not preclude the possibility of God, although the theory has no room for a "god-of-the-gaps" (one that is directly responsible for the as-yet-unexplained) or other scientifically and theologically suspect ways of keeping God's finger in the natural pie.

Pennock's restraint, patience, and thoroughness in taking on creationist arguments stand in marked contrast to recent authors who too glibly poke fun at what they think is mere superstition (and with whom I tend to agree). Unfortunately, like the authors of all recent books shoring up evolution against creationist inroads, Pennock is preaching primarily to the converted. Nevertheless, opening the eyes of bewildered scientists to the reasons for the recent creationist successes makes *Tower of Babel* worth reading. Perhaps it can give us the language by which we can defeat these new creationists in the court of public opinion, where it appears that—at least for now—the battle will be decided.

Genesis of Babel. Pieter Bruegel the Elder's interpretation (1563) of the tower that, in the Bible's account, led God to create the variety of languages.

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