the competitive dynamics that animated it. The book also contains lucid accounts of many of the advances in theoretical physics since the middle of this century — Feynman diagrams, renormalization theory, the explanation of the superfluidity of liquid helium, partons and quarks, the standard model — advances to which Feynman made important, fundamental contributions. Gleick's accomplishment in this area is uncommon because he is not a scientist by training, yet his presentation of the science is accurate and readily accessible to the general reader.

Gleick never met Feynman. His knowledge of his subject stems from interviews with members of Feynman's family, with colleagues and former students, and with friends dating back to Feynman's highschool and college days. He read and listened to taped interviews with Feynman that various historians had made earlier, in particular the extensive and remarkable interviews that Charles Weiner recorded in the late 1960s and mid-1970s. He studied videotapes of Feynman's lectures and television programmes, and pored over some 25 cartons of papers, notes and correspondence that Feynman had deposited in the archives of the California Institute of Technology. It is clear that Feynman was unusually gifted, highly original and inventive. But the vivid portrait that Gleick draws would not have been possible without access to the personal letters that Feynman had kept in his house. Gweneth, Feynman's wife, allowed Gleick to read the correspondence between Feynman and his parents, between Feynman and his first wife, Arline, and letters to Feynman from lovers and personal friends.

Feynman's relationship with Arline — his first girlfriend, his first and perhaps his only true love, and his first wife — shaped his subsequent life. Arline was diagnosed as having lymphatic tuberculosis while Feynman was at MIT. Despite the strenuous objections of his parents, the two got married before Feynman went to Los Alamos early in 1943. Throughout his stay there, Arline was in a hospital in Albuquerque and she died shortly before Trinity in 1945. Feynman never recovered from the loss, seemingly arriving at the conviction that he would never again be fulfilled in love. Two years after Arline died, Feynman — the supreme rationalist — wrote her a heart-rending love letter. His subsequent interactions with women were always affected by the scars incurred by the loss — until his marriage to Gweneth, the emptiness and yearning were filled by one-night stands and tempestuous, destructive love affairs. Similarly, in physics he came to accept human limitations: unification and, in particular, a theory of

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everything were, in his view, fantasies with which the community deluded itself. Physics consisted of a set of algorithms that answered with a high degree of certainty questions of the form: 'If I do this, what will happen?' Feynman searched for such algorithms with extraordinary courage and unshakeable integrity.

Gleick is captivated by Feynman's "genius". (Who wouldn't be?) At times he seems obsessed by the notion of genius and by the search for what constitutes its possession. He fails to find the holy grail, but does make clear that to understand Feynman one has to apprehend his peculiar connection to his social world and his distinctive intellectual relationship to the scientific community in general and the physics community in particular. In intellectual matters Feynman was able to straddle the gulf between self and community. He could adhere to many of the tenets, assumptions, forms of thought and styles of reasoning that characterized the theoretical physics of his day while also transcending their limitations. One aspect of Feynman's genius was that he could make clear what was obscure to most of his contemporaries. His doctoral dissertation and his 1947 *Reviews of Modern Physics* article that presented his path-integral formulation of nonrelativistic quantum mechanics helped to clarify in a striking manner the assumptions that underlie the usual quantum-mechanical description of the dynamics of microscopic entities. And he did this in the very act of transcending the usual formulation with a startling innovation. It may well be that his reformulation of quantum mechanics and his 'integral over paths' will turn out to be his most profound and enduring contributions. They have deepened considerably our understanding of quantum mechanics and have greatly extended the systems that can be quantized. And judging from the work of Michael Atyah and Ed Witten, Feynman's path integral has already substantially enriched mathematics and provided new insights into spaces of infinite dimensions.

Early on, Feynman also learned to walk the tightrope between his own psychological needs and the requirements of belonging to a community. He came to accept and appreciate the fact that the act of creation was for him also an act of consummate isolation.

The creative act depends on private visions and solitary constructions and always draws on the legacy and the resources of the community, be it in the arts, literature, technology or the sciences. We call people geniuses when their ability to synthesize these communal resources overwhelms us; and if the synthesis happens to result in a startling outcome, as in the case of Feynman, we are amazed and awe-struck. But by creating a category of people we label as geniuses, we are on a slippery slope that may lead us to believe that there is an innate quality attached to the attribution, when instead we should focus on its social and cultural dimensions. Rather than *Genius*, I would have called this impressive book *The Remarkable Life and Science of Richard Feynman.* □

S. S. Schweber is in the Department of Physics, Brandeis University, Waltham, Massachusetts 02254, USA.

Mathematics in the mind

Michael Berry

Pi in the Sky: Counting, Thinking, and Being. By John D. Barrow. *Oxford University Press: 1992. Pp. 317. £14.95, $25.*

MY son, a musical beginner, keeps getting confused about intervals: asked to play a fourth, he delivers a fifth. I suppose this is a widespread confusion, whose origin might lie in the absence of zero from musical notation. Intervals (n) therefore obey not the addition rule of ordinary arithmetic but $(n)+(m)=(n+m-1)$: a second plus a second equals a third. Realizing this, we suddenly see how deeply we have interiorized the conventions of elementary mathematics. One of John Barrow's aims is to trace the origins of these counting conventions in human (and animal) societies. This is part of a far more ambitious programme: understanding the meaning of mathematics and the role it plays in science.

By profession, Barrow is an astronomer and physicist, and the mainspring of this work is what Wigner called "the unreasonable effectiveness of mathematics". Wigner was referring to the mysterious phenomenon in which areas of pure mathematics, originally constructed without regard to application, are suddenly discovered to be exactly what is required to describe the structure of the physical world. Thus, Riemann's general formulation of the geometry of curved spaces was essential to Einstein's understanding of gravity; Heisenberg found that the symbolic arrays which in quantum mechanics represent observable quantities were the matrices that had been invented decades earlier; and now recondite aspects of the distribution of prime numbers might well provide the link between quantum mechanics and newtonian chaos.

Such connections raise many questions. Is mathematical truth invented by mathematicians, or does it already exist in the world, to be discovered when our minds become sophisticated enough? If discovered, where is it beforehand? What is its relation to the matter whose behaviour it describes so well? Is there any inapplicable mathematics?

Barrow does not answer these questions, but gives a careful and perceptive account of their background and the philosophies they have stimulated. He starts, appropriately enough, with an anthropological and historical analysis of counting and calculation, focusing on the tricky question of whether such skills are innate, and would inevitably develop in any human society, or whether they arose 'accidentally' in one (or several) societies, and diffused to the others. The latter is, he thinks, more plausible. Central here are the inventions (discoveries?) of place values and of zero, by the Babylonians and Hindus 5,000 years ago, leading via the mediaeval Arabs to the decimal system we use today.

Because mathematics is the most precise embodiment of systematic thought, it was natural to try to prove that it has a solid foundation in logic and is perfectly consistent. The story of these attempts has often been told. How Frege, Russell and Whitehead tried to 'derive' mathematics from logic almost a century ago, and how this attempt was complicated by the irritating paradoxes of self-referential sets ('If the barber shaves everyone who does not shave himself, who shaves the barber?'). How Hilbert took up the challenge by trying to prove the consistency of mathematics from within, by formalizing its symbols and deductive steps. How "all the noonday brightness of this confident picture of the formalists' little mathematical world was suddenly extinguished" by Gödel's proof in 1931 that the set-theory paradoxes make it impossible for a sufficiently complicated system to be proved consistent from within. These ideas are central to modern notions of randomness as the inability to compress information, and may have implications for our attempts (in my view doomed) to find a compact encoding of the physical universe as a 'theory of everything'. Barrow's account of these matters is lucid and engaging.

After pointing out that "formalism is lacking in two crucial respects" (it does not explain the usefulness of mathematics and its relation to the minds of mathematicians), Barrow turns to inventionism. This "amounts to the claim that mathematics is a branch of ... psychology". It makes "mathematical truth dependent upon time and history", and "one cannot help but feel that humanity is not really clever enough to have 'invented' mathematics".

A chapter is devoted to Brouwer's programme of intuitionism, where the natural numbers are regarded as unarguably 'given', and the aim is to build the rest of mathematics "by step-by-step deductions using a finite number of steps". This brought him into collision with Hilbert, who believed that such a philosophy, which disallowed infinite processes such as arguing by *reductio ad absurdum*, would fatally impoverish and weaken mathematics. Hilbert's attempt to enforce political correctness and to expel Brouwer from the editorial board of *Mathematische Annalen* provoked an absurd and bitter controversy that Einstein called the "war of the frogs and mice".

Finally, Barrow explores the Platonic position that mathematical abstractions exist "in a realm of non-spatial, non-mental, timeless entities". He concludes, albeit somewhat uneasily: "Our ability to create and apprehend mathematical structures in the world is merely a consequence of our own oneness with the world".

I admit to finding some of Barrow's arguments hard to follow not because of their content but because of his habit of using very long sentences unadorned by punctuation whose verbs are hard to find and whose meanings therefore hard to unravel. Worse, some sentences are incomplete, and there are many spelling mistakes. Quotations abound. Some are witty and apposite, but why propagate Spiro Agnew's abysmal "An intellectual is a man who doesn't know how to park a bike"?

These are, however, minor criticisms, and I warmly recommend Barrow's brave attempt to gather up the many loose threads of this elusive subject — a subject so central to our scientific culture — and to grasp the whole of it. □

Michael Berry is in the Department of Physics, University of Bristol, Bristol BS8 1TL, UK.

Einstein as lover

Joseph Schwartz

Albert Einstein and Mileva Marić: The Love Letters. Edited and with an introduction by Jürgen Renn and Robert Schulmann. Translated by Shawn Smith. *Princeton University Press: 1992. Pp. 107. $14.95, £12.50.*

THIS elegantly published volume of letters between the young Einstein and the young Marić is a spin-off from the first two volumes of a planned 35 volumes containing some 43,000 documents lying in the Einstein archive. A lovely introduction by Jürgen Renn and Robert Schulmann, coeditors of the project, draws our attention to the unique personality of Marić and her central contribution to the Einstein success story. The meticulous scholarship of the notes is wonderful, particularly the inclusion of the dates of virtually all the characters in this first act of the Einstein drama. And the letters themselves are a treat, a window into the early development of the man who became the most celebrated scientist in history. But what, when all is said and done, does this correspondence tell us?

The Einstein we see here is bubblingly optimistic, reassuring, high-spirited, confident about life. For the first time we have an Einstein with sexuality: "Oh my! That Johnnie boy!/So crazy with desire/ While thinking of his Dollie/His pillow catches fire" (letters 19); "How beautiful it was the last time you let me press your dear little person against me in that most natural way" (letter 33). Albert is happy in his sexual relationship with Marić and the letters show it.

There is a not entirely happy story here, however, about two lovers, one who thrives, the other who gets increasingly submerged by life. We meet them both as students of physics. She, a late entrant from the distant provinces of undeveloped Serbia, is three-and-a-half years his senior. He is youthful, exuberant. No obstacle is too great. She, while available for emotional and sexual involvement, is unhappy, feeling that her provincial background has irreversibly limited her chance in physics. While Einstein is absorbing with great fascination the nuts and bolts of doing physics, Marić is distant, observing wistfully the spectacle of her university lecturers: "human beings are so clever and have accomplished so much as I have observed once again here in the case of the Heidelberg professors" (letter 1).

As we journey with these lovers over a