

academia. Undaunted, for many years she lectured in Erlangen and, from 1915, at the University of Göttingen — often for free.

At the time, that city was the centre of the mathematical world, largely due to the presence of two of its titans — Felix Klein and David Hilbert. But even when Noether was being paid to teach at Göttingen and making her most important contributions, fate and further discrimination intervened: Hitler took power in 1933 and she was fired for being Jewish. She escaped to the United States and taught at Bryn Mawr College in Pennsylvania, until she died in 1935, at the age of just 53.

Noether devoted her career to algebra and came to see it in a striking new light. “All of us like to rely on figures and formulas,” wrote Bartel van der Waerden, her former student, in his obituary of Noether. “She was concerned with concepts only, not with visualization or calculation.”

Noether saw maths as what are now called structures. To her, the characteristics of a structure’s components — be they numbers, polynomials or something else — mattered less than the networks of relations among an entire set of objects. This enabled her to give proofs that applied to more general structures than the original ones, and which revealed unseen connections.

It was a new and elegant approach that changed the face of algebra. And Noether realized that it could influence other parts of maths. One was topology, a field in which “she published half a sentence and has an everlasting effect”, one mathematician wrote. Before Noether, topologists had been counting holes in doughnuts; she brought to bear the full power of her structures to create something called algebraic topology.

The results that Noether published 100 years ago were, for her, a rare foray into physics, in which she was not particularly interested. Albert Einstein had just developed his general theory of relativity, and was struggling to understand how energy fitted into his equations. Hilbert and Klein were working on it, too, and asked Noether for help.

That she did help is an understatement. Noether’s expertise in

symmetry led her to discover that the symmetries of a physical system are inextricably linked to physical quantities that are conserved, such as energy. These ideas became known as Noether’s theorem (E. Noether *Nachr. d. Ges. d. Wiss. zu Göttingen, Math.-phys. Kl.* **1918**, 235–257; 1918).

As well as answering a conundrum in general relativity, this theorem became a guiding principle for the discovery of new physical laws. For example, researchers soon realized that the conservation of net electric

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charge — which can neither be created nor destroyed — is intimately related to the rotational symmetry of a plane around a point. The impact was profound: those who created the standard model of particle physics, and the researchers who attempt to extend it, think in terms of Noether’s symmetries.

Some biographies inaccurately portray Noether as a somewhat helpless genius at the mercy of men’s charitable actions. In reality, she was an assertive personality, recognized leader and the first female plenary speaker at the renowned International Congress of Mathematicians.

The status of women in mathematics and science has improved since Noether’s time, but bias and discrimination remain. Too few leading female mathematicians receive the recognition they deserve. (Only one woman, Maryam Mirzakhani, has received the Fields Medal, and none has won the Abel Prize — the field’s top awards.) Noether is an inspiration: including to UK mathematician Elizabeth Mansfield, who co-organized the London meeting and works on modern extensions of Noether’s work.

We don’t know how many potential Emmy Noethers have been unfairly denied the chance to show their talents. More people should know — and should celebrate — one who changed the scientific world against the odds. ■

Experts needed

Pakistan needs the courage to listen to independent expertise, including on science.

It took US President Donald Trump 18 months to announce a science adviser. By contrast, Pakistan’s new prime minister, Imran Khan, is widely expected to appoint a science minister in the early stages of his administration. It will be a welcome move: scientific expertise will be essential in shaping the country’s future. But whoever it is will have a fight on their hands to ensure that inclusive and evidence-based advice prevails.

Khan has come into office promising anything but business as usual. In an echo of America’s New Deal and the first post-Second World War European governments, he has pledged a welfare state, affordable health care, school reform, improvements to agriculture (the backbone of the economy), and an axe to public-sector corruption.

To do all this, his government will need medical researchers and health-care specialists to advise on plans for a national health service; primary- and secondary-school educationalists to work out how best to get every child into a good school; and science and innovation policy experts to guide academic researchers on the path to quality improvements and better community engagement.

Khan has repeatedly said that he will appoint the best people to top jobs. On that score, however, his ministerial team of mostly political appointees has had mixed reviews. What the new ministers lack in particular is a wide-ranging and credible network of experts to call on. There is a shortage of people — and especially women — from high-level academic and other professional backgrounds plugged into policymaking. Khan knows this and has appealed for help. So far, the

calls have been heeded by economists in particular, as evidenced by the prime minister’s 18-member Economic Advisory Council — albeit an all-male one.

But one obstacle to gathering expertise is the state’s persistent failure to confront rising intolerance, particularly against minorities. In a backwards move, Khan last week bent to the will of the TLP, a far-right political party that attracted more than 2 million votes in July’s elections, and he removed Princeton University economist Atif Mian from the Economic Advisory Council. Mian’s nomination was challenged by the TLP solely because he belongs to the Ahmadiyya, a much-persecuted minority Muslim community. Mian is highly regarded and his dismissal has been roundly condemned; the other two international members of the council resigned in protest.

The move signals an unwillingness by Khan to appoint advisers who can speak truth to power — and that could have a wider, chilling effect. It will make other independent experts think twice about joining Khan’s cause or advocating vital but unpopular reforms.

The new government has ratcheted up expectations with a list of tasks on which lives depend. One of Pakistan’s most urgent challenges, for example, is to improve the availability and quality of water. Agriculture uses 90% of supplies, but a population of 200 million — and rising — means that the country is officially classified as ‘water-scarce’. Climate change is projected to reduce water availability further, and poor water quality is a major source of disease. In response, the government wants to build more dams, but the expert consensus is that the cost of dams outweighs the benefits, and so other solutions must be sought.

Will that type of expertise be listened to, and will Pakistan forge the right path? Right now, citizens at home — and many in the international community — are willing Imran Khan’s nation-building project to succeed. As a star cricketer, Khan once described his style of play as that of a cornered tiger. He needs to muster this legendary courage and call out bigotry; otherwise, whatever goodwill exists towards his government will evaporate very fast indeed. ■