reach a red tab, which could then be pushed to access a sugar treat (Fig. 1b). Over periods of 12 or 24 days, no bee across 3 colonies tested worked this out. Then, through a painstaking process, the authors used rewards to train nine bees to learn the solution and thus become demonstrators for the other bees. Strikingly, 5 of the 15 bees that were then exposed to demonstrators learnt the task themselves. These are small sample sizes, but the point is clear — the task was exceptionally hard to learn alone, yet some bees could solve it through social learning.

It is possible that some individuals in the studies might have innovated the task solution had they been given more time. After all, 3 months is not that long a time frame for a chimpanzee that might live for 40 years or more. By contrast, the average bumblebee spends only 8 days of its life foraging, so the 12–24 days in Bridges and colleagues' study might be as close as scientists will ever get to testing what animals are capable of in their lifetimes.

But what if more individuals had participated in the experiments? This demonstrates a general difficulty in testing the hypothesis based on the zone of latent solutions. How can a researcher ever be satisfied that a task is too difficult to solve alone? And can we really define the zone of latent solutions for a particular species, given that cognitive abilities, skills and knowledge vary widely between individuals in that species, depending on their genes and developmental experiences[5,6]?

Of course, the social transmission of behaviours acquired through human training does not show that bumblebees or chimpanzees socially learn such complex skills in the wild. Moreover, both studies involved a single episode of social learning, so they cannot explicitly test the potential for the progressive improvements in skills that characterize cumulative culture. The chimpanzee research has intriguing parallels with natural behaviours such as nut-cracking — a multi-step skill that some suggest is too complex for chimpanzees to learn alone and so must be an outcome of cumulative culture[7]. However, rather than telling us about cumulative culture in bumblebees and chimpanzees, a strength of these studies might be what they reveal about humans.

People habitually overestimate their abilities relative to those of other animals and are drawn to 'silver bullet' explanations of human cognition and culture[8]. This research suggests that the ability to learn from others what cannot be learnt alone should now join tool use, episodic memory (the ability to recall specific past events) and intentional communication in the scrapheap of discarded silver bullets[8]. There is also no need to appeal to specialized forms of social learning, such as imitating others' body movements — the bumblebees learnt simply because by following closely behind knowledgeable demonstrators, they gained experience of the task. Many researchers studying humans are reaching similar conclusions. For instance, experiments show that the imitation of body movements is not necessary to achieve cumulative improvements in tool designs[9,10].

If chimpanzees and bumblebees can learn from others what cannot be learnt alone, then this ability is unlikely to be an explanation for humanity's distinctive cumulative culture. Rather than an explanation, it might instead be an outcome — cumulative culture produces products, such as the laptop I am using now, that are much too complex for any one of us to invent alone. Perhaps it is time to abandon silver bullets and focus instead on unravelling how the co-evolutionary web of feedback between innovation, social learning and social structure gives rise to the complex culture on which humans all depend[5,8,10].

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In retrospect

Epstein–Barr virus at 60

Lawrence S. Young

The 1964 discovery of Epstein–Barr virus shed light on factors that contribute to human cancer. Subsequent studies set the stage for finding ways to diagnose and treat cancer, and revealed how immune defences control viral infection.

This month marks the 60th anniversary of the discovery of Epstein–Barr virus (EBV), the first virus shown to cause cancer in humans. In March 1964, Anthony Epstein, Yvonne Barr and Bert Achong presented findings[1] in *The Lancet* which reported the identification of these virus particles in cancer cells, grown *in vitro,* that were taken from an aggressive type of blood cancer (lymphoma) found in children living in central Africa.

The possibility that an infectious agent might cause cancer originated with Peyton Rous's discovery in 1911 that a virus — called Rous sarcoma virus — caused soft-tissue tumours (known as sarcomas) in chickens[2]. Although this report was met with much scepticism, the observation initiated a series of studies confirming that viruses can cause cancer in animals, but such a role for viruses in humans remained elusive.

The identification of EBV, 53 years later, was a landmark discovery in the understanding of human cancer, providing key insights into processes that can drive tumour formation. The finding also encouraged further interest in the field of tumour virology resulting in the identification[3] of other human-cancer-associated viruses, including human papillomaviruses and hepatitis B virus. It is now estimated that viruses cause between 10% and 15% of human cancers worldwide[3,4]. These viruses provide crucial targets for diagnosis, therapy and prevention.

The discovery of EBV owes much to serendipity[5,6]. During the 1950s, Epstein had been working on Rous sarcoma virus — an unfashionable topic at the time — because he was convinced that viruses would also have a role in human cancer. By chance, Epstein, who was then working at the Middlesex Hospital in London, attended a lecture on 22 March 1961 by Denis Burkitt, a surgeon who had been working in Africa. Burkitt showed that the distribution of a type of lymphoma that affected children across Africa was dependent on climatic factors. Epstein concluded that the connection to climate noticed by Burkitt might mean that an insect was involved in spreading a tumour-promoting virus.

Burkitt agreed to send biopsy samples of the tumour, now known as Burkitt lymphoma, from Kampala for analysis in Epstein's

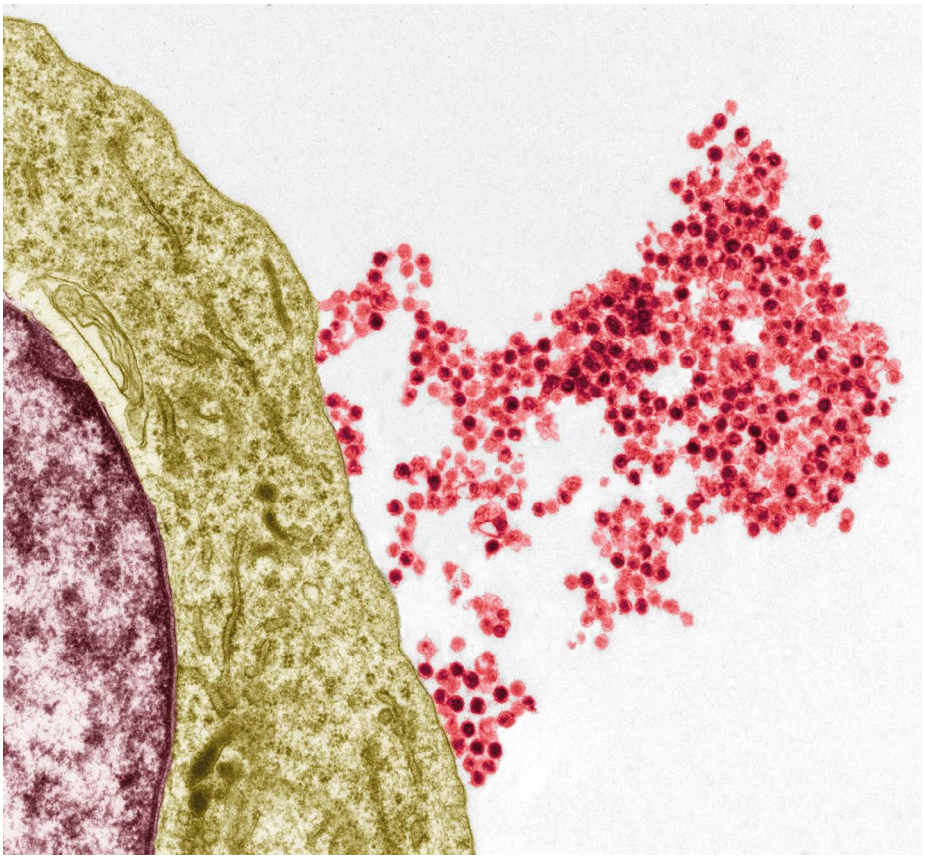
laboratory. After many failed attempts to identify a potential virus residing in fresh biopsies, Epstein managed to grow the tumour cells *in vitro*, hoping that this would encourage any resident dormant (latent) virus to replicate and reveal itself. He examined these cells using an electron microscope and immediately identified replicating viruses that had a shape similar to that of a herpesvirus. After this observation was published in *The Lancet* in 1964, the virus (Fig. 1) was subsequently named Epstein–Barr virus (EBV).

EBV's role in cancer is not restricted to Burkitt lymphoma. A combination of studies that examined blood samples to determine antibody responses to EBV and molecular analyses directly probing for the presence of the virus in tumour cells revealed that EBV is associated with a variety of cancers. EBV is implicated as a cause of lymphomas that originate from immune cells called B cells and T cells. Some of these cancers arise because of a compromised immune system, for example in people who have had an organ transplant and are receiving immunosuppressive drug therapy, such illness is called post-transplant lymphoproliferative disease (PTLD). These types of cancer also arose in individuals who had HIV before effective therapies for HIV were available[6,7].

Aside from these various cancers associated with immune cells, EBV is also involved in the development of tumours originating in epithelial cells that line body surfaces. These include a type of cancer called nasopharyngeal carcinoma (NPC), a tumour that develops at the back of the nose and that has high incidence in southern China and southeast Asia. EBV is also linked to around 10% of stomach cancers[6–8]. A notable feature of cancers associated with EBV and other viruses is that resource-limited countries generally have a higher burden of these tumours compared with resource-rich nations[4]. It is estimated that EBV is responsible for around 200,000 cancer cases annually across the globe and that 1.8% of all cancer deaths are due to EBV-attributable malignancies[4,9,10].

However, EBV is not an infection that is restricted only to individuals who have cancer, it is also the most common persistent viral infection in humans, with around 95% of the world's population sustaining an asymptomatic lifelong infection. Although most people are infected with EBV early in life and have minimal symptoms, infection in adolescence or early adulthood can result in a condition called infectious mononucleosis, also known as glandular fever[6,7].

Once a person is infected by EBV, it remains latent for life in a small proportion of immune cells called memory B cells. Occasional virus replication occurs in B cells that become activated in lymphoid tissues or in differentiating epithelial cells in the nose, mouth and throat[6,11]. The immune system, particularly



STEVE GSCHMEISSNER/SPL

Figure 1 | Epstein–Barr virus. The virus (red) has been shed from a B cell of the immune system.

in terms of its defences mediated by T cells, has a key role in controlling EBV in host cells[12]. Relaxation of this immune control, as occurs in transplant recipients, results in excessive EBV infection of B cells, which drives the development of PTLD. The complex interplay between EBV and the immune system can also manifest itself in other unexpected ways as demonstrated by the pivotal role of the virus in the development of multiple sclerosis[13] and its potential contribution to conditions such as long COVID and chronic fatigue syndrome[14].

How does a virus that infects most of the world's population cause cancer? The International Agency for Research on Cancer didn't designate EBV as a cancer-promoting agent (carcinogen) until 1997 after the direct role of EBV infection in the development of B-cell lymphomas was confirmed in children who have a rare genetic disorder called X-linked lymphoproliferative disease (see go.nature.com/43hkaus).

The tumours associated with EBV can arise due to impaired immune control of the virus and defective regulation of the virus life cycle owing to other genetic or environmental factors. The convergence of multiple factors that are responsible for tumour development is evident in EBV-associated cancers, particularly in those that occur in individuals with a functioning immune system. For example, infection with a malaria-causing parasite and the resulting rearrangement (translocation) of genes on a chromosome, involving the cancer-promoting *MYC* gene, cooperate with EBV to drive Burkitt lymphoma[15]. In NPC, a mix of genetic events (for example, individuals of Chinese heritage are often affected) and epigenetic events (changes to the DNA–protein complex called chromatin) and some factors associated with diet and smoking, result in EBV establishing an aberrant latent infection in epithelial cells of pharyngeal tissue, leading to malignant changes[6,8].

We have learnt a lot about the biology of EBV over the past 60 years. The surprising ability of EBV to induce uncontrolled proliferation of B cells in cell culture, leading to the establishment of continuously growing cell lines *in vitro*, confirms the cancer-causing ability of the virus and provides a valuable tool for dissecting the functional role of individual virus genes in normal infection and in cancer.

Twenty years after its discovery, EBV was the first herpesvirus to be completely sequenced and at that time the largest piece of DNA ever sequenced, with a length of 172 kilobases[16]. The virus encodes more than 85 genes with only a limited set of 'latent genes' being consistently expressed in human cancers. Some studies have implicated genetic variations in EBV strains in the development of NPC and possibly other virus-associated diseases[17]. Aside from deepening our understanding of herpesvirus biology and of cancer-promoting mechanisms, the study of EBV has provided an

insight into the general immunology of virus infection, as well as shed light on the strategies used by viruses and cancer to evade immune responses.

The association of EBV with cancer has been exploited for clinical benefits, with implications for the diagnosis and treatment of all cancers. The measurement of EBV DNA in the blood of people who have NPC provides a valuable prognostic biomarker and this can also be used as a screening test to detect early-stage NPC[8]. This approach provided the foundation for the development of technologies that measure tumour DNA in the bloodstream for the early detection of more-common cancers. Gaining a better understanding of the immune response to EBV led to the successful development of T-cell-based therapy for PTLD and other EBV-associated tumours, an approach that is now being more-widely explored for cancer therapy[18].

The association of EBV with multiple sclerosis has reignited interest in the possibility of both preventative and therapeutic vaccines that target EBV[13,19]. Original studies of a preventative vaccine against EBV demonstrated protection from infectious mononucleosis but not from the initial (primary) asymptomatic EBV infection. Achieving complete protection from EBV infection will probably require a more efficient immune response, such as one generated by the EBV vaccines currently under development that encode multiple virus proteins[20]. There have been many attempts to develop therapeutic vaccines for the treatment of EBV-associated cancers but with limited success. However, new approaches to vaccine development, particularly those using messenger RNA, hold promise for the both the prevention and treatment of EBV-associated diseases and are currently being tested in clinical trials[12,19,20].

The discovery of EBV 60 years ago led the way to firmly establishing that viruses can cause cancer in humans. Aside from shedding light on the role of infection in cancer, EBV's intimate relationship with the immune system has provided valuable insights into the regulation of immune responses. Another downside of this close interaction is EBV's contribution to multiple sclerosis and possibly to other autoimmune diseases. Efforts to develop effective vaccines and antiviral drugs raises hope for the prevention and management of EBV-associated diseases and for the wider elimination of all cancers caused by viruses.

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Condensed-matter physics

Magnetic whirlpools offer improved data storage

Qiming Shao

Complex magnetic structures called skyrmions have been generated on a nanometre scale and controlled electrically — a promising step for fast, energy-efficient computer hardware systems that can store large amounts of data. **See p.522**

Every electron has an intrinsic angular momentum known as its spin, and the direction of this spin — either up or down — is used to store the bits of information that make up hard-disk drives and magnetic tapes. But these bits are moved by rotating the host material mechanically, which is slow and can be unreliable. Magnetic skyrmions are complex whirlpool-like arrangements of spins that can be controlled electrically on a nanometre scale, making them promising candidates for storing large amounts of data that can be accessed rapidly[1]. On page 522, Chen *et al.*[2] report an all-electrical way to read and write information by encoding it in a single nanoscale skyrmion, paving the way for low-power data storage on a massive scale.

The ability to control a magnetic state electrically is made possible by a phenomenon called giant magnetoresistance. This Nobel-prizewinning discovery kicked off the research field known as spintronics[3]. Giant magnetoresistance is a huge change in electrical resistance that is induced by a change in the magnetic state of a material, and it occurs in multilayer systems that comprise at least two magnetic layers separated by one non-magnetic layer. When the spins in the two magnetic layers point in the same direction, the system has a low resistance; when they point in opposite directions, the system has a high resistance. This difference in resistance — usually less than 20% at room temperature[3] — determines how easily one can distinguish between the two configurations.

A related phenomenon called the tunnel magnetoresistance effect can bring about a difference of more than 100%. This effect can be induced in magnetic tunnel junctions — structures that consist of a non-magnetic layer sandwiched between two magnetic layers (Fig. 1a). The spins in one magnetic layer are pinned to point upwards, whereas those in the other layer can be switched between up and down by applying an external magnetic field or a voltage, resulting in configurations that are parallel and antiparallel to the pinned spins, respectively. The latest hard-disk drives and magnetic tapes use this principle to read magnetic states quickly and reliably. But writing magnetic states still requires mechanical rotators to position the magnetic bits that need to be written, resulting in slow speeds, high energy costs and low reliability.

Skyrmions could provide a solution: these intricate spin textures can be driven by an electrical current[1], so a magnetic tunnel junction that has a skyrmion in the place of the switchable (free) spin layer could enable rapid and efficient reading and writing of information. But this would require nanoscale skyrmions to be generated at room temperature in a structure that has high tunnel magnetoresistance — a feat that has proved elusive despite some admirable efforts[4,5]. So far, only large skyrmions have been induced in such structures[6], and