stiffnesses (see Fig. 5 of the paper[1]). The robot's legs consist of chambers that deform in a predefined direction when deflated and inflated; sequential inflation and deflation therefore results in a walking motion. For both objects, the use of multiple parallel nozzles was instrumental in reducing the printing time. This was important because the printing fluids start to harden continuously once made, limiting the window for using them.

Skylar-Scott and colleagues' multi-material, multi-nozzle technique could have major implications for the development of 'architected' materials[7] — those that exhibit exotic properties arising from their engineered, periodic substructures rather than their chemistry. Examples include materials that are extremely light yet strong[8], and materials whose mechanical, optical or acoustic properties can be tuned by reconfiguring their internal structures[9]. Most architected materials so far have been made from a single non-architected compound. The ability to control the make-up of objects at a microscopic level (by printing combinations of voxels of different substances) opens up a new playing field, in which more and innovative functionalities can be programmed into the same architected material. This might lead to the production of architected materials that exhibit more machine-like behaviour than is currently possible[10].

But we are not there yet. The available library of printable materials, and the range of properties represented, needs to be extended — for example, to include materials that have a variety of electrical and thermal conductivities, or that swell when they absorb a solvent. Moreover, at present, the spacing between the nozzles in the multi-nozzle printheads is unchangeable, and all the nozzles eject fluid simultaneously and at the same rate. This means that Skylar-Scott and colleagues' system speeds up printing only for periodic structures in which the spacing between the nozzles determines the size of the periodic components. A different multi-nozzle printhead will be needed to produce structures that have other periodicities.

If the spacing between the nozzles was increased, then an alternative application of the multi-nozzle system could be to print exact copies of the same object in parallel. Work will also be needed to increase the flexibility of the technology, by making it possible to independently program the flow through each nozzle in a printhead, as is the case for inkjet-based methods.

Skylar-Scott *et al.* have pushed the boundaries of achievable speed and materials in additive manufacturing technologies. The work brings us closer than ever to being able to control the composition, geometry and properties of structures so small that they cannot be seen by the naked eye. This breakthrough is not merely a practical advance: it will change the way we design, build and think about functional devices.

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Learning

A genetically tailored education for birds

Ofer Tchernichovski & Dalton Conley

The ability of birds to learn a song depends not on their genes alone, but also on whether their genetic make-up is well matched to that of their singing teacher. This discovery sheds light on how gene–environment interactions affect learning.

The belief that some people are born gifted and others are fated to be mediocre is deeply rooted in our culture. But the influence of genes on learning is not straightforward. Writing in *eLife*, Mets and Brainard[1] describe how learning can be enhanced in songbirds by tailoring tutoring strategies to match the genetic biases of individuals. The authors' study suggests that there are not necessarily 'high-quality' or 'low-quality' gene sets when it comes to learning — instead, certain sets of genes are better or worse fits for particular learning environments.

A polygenic score is an estimate of an individual's propensity to display a given trait, taking into account all of his or her genes. These scores have been viewed by some as a way to assess a baby's genetic potential to develop complex disorders such as schizophrenia[2]. They have also been used to assess educational success, and can currently explain about 13% of the variation in the number of years of schooling that individuals in a population will complete[3]. But we are a long way from a genomic analysis that could direct specific educational investments or predict which children would benefit the most. Working this out in humans is dauntingly hard, because we cannot experimentally control genes and environments simultaneously.

However, interactions between genetics and learning are not unique to humans. Young songbirds acquire their vocal repertoire by imitating songs produced by adults. For birds, as for humans, learning is a social and cultural process — as in spoken language, vocal learning across generations produces local cultures of song dialects. Accurate learning is crucial for birds because those that do not acquire the local dialect are less likely to attract mates[4].

Experimental systems have been established that allow researchers to control both the genetics and the learning environment of songbirds from an early age, yielding insights into how the two interact. These systems have revealed, for example, that when birds are raised away from their parents and 'tutored' by song playbacks, the tempo of their songs is strongly influenced by their genetics[5]. By contrast, the influence of genetics on tempo is much weaker when a bird is raised by an adult tutor that actively guides the youngster[6]. Thus, a picture has emerged of an interplay between genetics and learning experience.

Mets and Brainard set out to pin down this relationship in more detail, using a population of Bengalese finches (*Lonchura striata domestica*) that had varied song-learning abilities. First, they compared how well finches tutored by their own parents learnt a song, compared with birds whose eggs had been moved into that nest before hatching. When birds were tutored by their own fathers, they generally learnt better than did fostered birds, suggesting that a match in genetic propensity for learning is key to how well birds learn songs.

The authors found that cross-fostered birds learnt well if their adoptive tutor had a song that was similar in tempo to their own. This result indicates that an interaction between

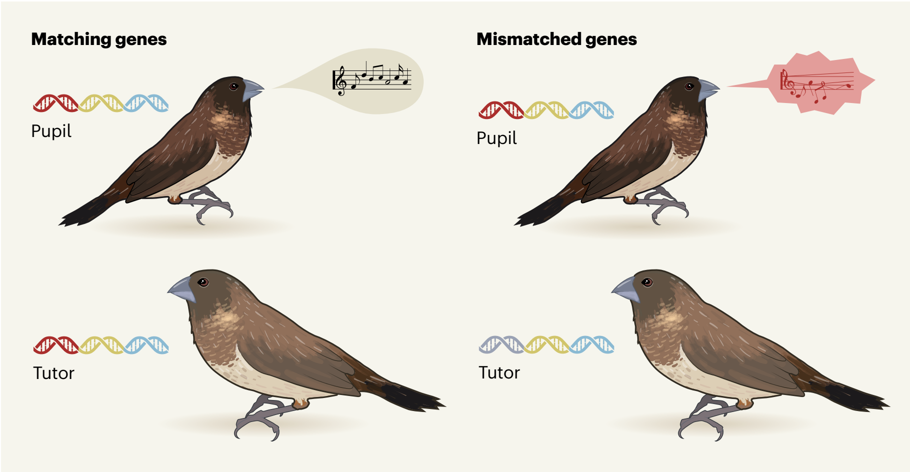

Figure 1 | How genetics and teaching style intersect. Mets and Brainard[1] show that a songbird's ability to learn depends on whether its genetic propensity for learning matches that of its tutor. Birds genetically predisposed to sing at a fast tempo (DNA beginning with the red section) learn best from birds that also have a genetic propensity to sing fast, and birds predisposed to sing at a slow tempo learn best from slow-singing birds (not shown). Poor singers are the result of a mismatch between the gene sets that determine singing speeds in the tutor and pupil.

genes and experience explains much of the variation in learning outcomes. It seems that certain birds are genetically tuned to learn and produce slow songs, whereas others are wired for fast songs. Giving a 'slow' bird a fast tutor does him or her no favours; the same is true in reverse (Fig. 1).

To rule out the possibility that the results reflected a difference in how fathers behaved towards their own offspring as opposed to their fostered tutees, Mets and Brainard reran the experiment using a computer-based tutoring system. As shown previously, when all birds were tutored with a standard synthetic song, there was a strong genetic variability in learning propensity. The authors demonstrated that those genetically predisposed to acquire a song with a tempo similar to that of the synthetic song learnt much better than 'faster' and 'slower' birds. Varying the tempo to match the tempo characteristic of the bird's biological father improved learning.

It might be imagined that the most brilliant birds would be able to learn at any tempo, whereas others would learn well only when tutored at a slow tempo. But Mets and Brainards' results demonstrate that this is not the case. Most remarkably, birds that were genetically tuned to sing slowly were not inherently worse learners. In fact, they often learnt better than the fast birds once the tutoring tempo 'resonated' with them.

The authors' results indicate that, if we can work out how to match genetic predisposition and 'tutoring' style among humans, we might be able to enhance learning for children. Indeed, some observational results in humans suggest that there is an interaction between the polygenic score for education of a child and that of their mother[7] — high polygenic scores for both mother and child are associated with higher educational achievement than is a high score for the child or the mother alone. Of course, in extreme cases, some children (and birds) might be inherently worse learners, no matter to whom they are matched.

It is difficult to be a child in today's super-competitive world. Mets and Brainard's results raise the possibility that even a modest mismatch between tutoring pace and genetics can hamper learning. Of course, we do not yet have a good way to discover how interactions between a person's genes and their environment will affect learning[8,9]. But it is imperative to ensure that human genetics studies of learning are sufficiently nuanced, and acknowledge the huge effect of the environment — including the possibility that a child might be in the wrong learning environment for their genes.

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Immunology

One ring to rule them all

Ferenc Livak & André Nussenzweig

Distant DNA regions are juxtaposed and joined to form diverse immune-system genes encoding antibodies and T-cell receptors. It seems that both types of gene form by relying on DNA extrusion through a protein ring called cohesin. **See p.385**

Our ability to fight the multitude of potential disease-causing agents that we encounter depends on a process called recombination, which can occur in different ways. Recombination manipulates DNA sequences to enable our bodies to generate an enormous diversity of the immune system's recognition components: antibodies and T-cell receptors (TCRs). Two papers in *Nature* from the same laboratory, by Zhang *et al.*[1] and Zhang *et al.*[2] (page 385), reveal an unexpected similarity in how these types of recombination event occur.

In developing immune-system cells, a process called V(D)J recombination rearranges DNA sequences to assemble genes that will encode either an antibody or a TCR, using a large pool of three classes of gene segments, termed V, D and J. These gene segments are flanked by evolutionarily conserved DNA sequences called recombination signal sequences (RSSs), which direct the enzyme RAG to join together one V segment and one J segment, and sometimes also one D segment, in an astonishing variety of combinations. The intervening DNA between these joined segments is usually deleted, although in rare instances it is instead inverted and retained when two gene segments are joined. This recombination process enables antibodies and