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The Beginnings of Biomimetics

It's not what you look at that matters, it is what you see.

Henry David Thoreau

At its simplest, biomimetics is the design and production of materials, structures, and systems that are modelled on biological entities and processes. The concept of biomimetics stems from the realization that microbes, plants, and animals have been continuously evolving to cope with environmental and other challenges. The design challenges associated with vision, movement in diverse environments, temperature control, and detection of predators and/or prey have already been solved in a myriad ways over millions of years of evolution, providing rich opportunities for development of biomimetic and bioinspired materials. The diversity in form and function of living things is such that they have evolved solutions to most of the challenges that face humans today. We just have to look for those solutions! Janine Benyus pioneered this approach to problem solving in her 1997 book entitled *Biomimicry: Innovation Inspired by Nature* – biomimicry being an alternative name for biomimetics.

The term biomimetics was devised over 40 years ago by American physicist Otto Schmitt. For him, biomimetics represented a biological approach to engineering in contrast to 'biophysics', which describes an engineering and physical approach to biology. A related term is 'bionics' but, following the 1974 television series *The Six Million Dollar Man*, this has come to mean electronically operated artificial body parts. In 2015, George Whitesides of Harvard University pointed out that scientists often take inspiration from the capabilities of plants and animals and attempt to mimic some of their functionality using simplified and probably different mechanisms. He calls this 'bioinspiration' and defines it as 'using phenomena in biology to stimulate research in non-biological research and technology'. The subject matter covered in this book is a mixture of bioinspiration and biomimetics. The novice reader might be interested to know that there is a journal that covers these two topics and, unsurprisingly, it is called *Bioinspiration and Biomimetics*.

Benyus has pointed out that there are two types of biomimetics: forward and reverse (Figure 1.1). In forward biomimetics, we see an innovation that has evolved in nature and wonder how we might use it. A good example of this is the invention of Velcro® (see Section 1.2). In reverse biomimetics, we are faced with a problem and turn to nature for a solution (Figure 1.2). Many examples of this approach are presented in the chapters that follow including the design of the Japanese 'bullet trains' (Chapter 2) and glass that prevents bird strikes (Chapter 3).

Biomimetics: Nature-Inspired Design and Innovation, First Edition. Sandy B. Primrose.

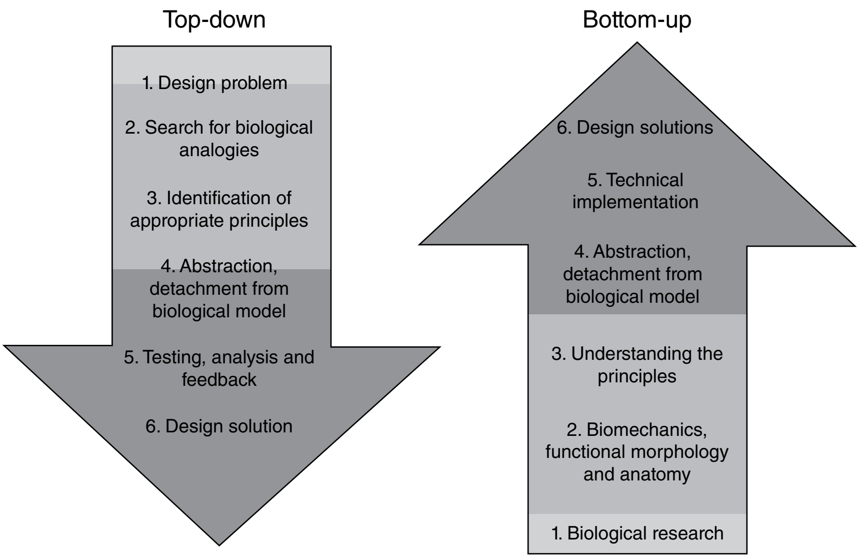

Figure 1.1 Biomimetics approaches. *Source:* Reproduced courtesy of the Biomimicry Institute.

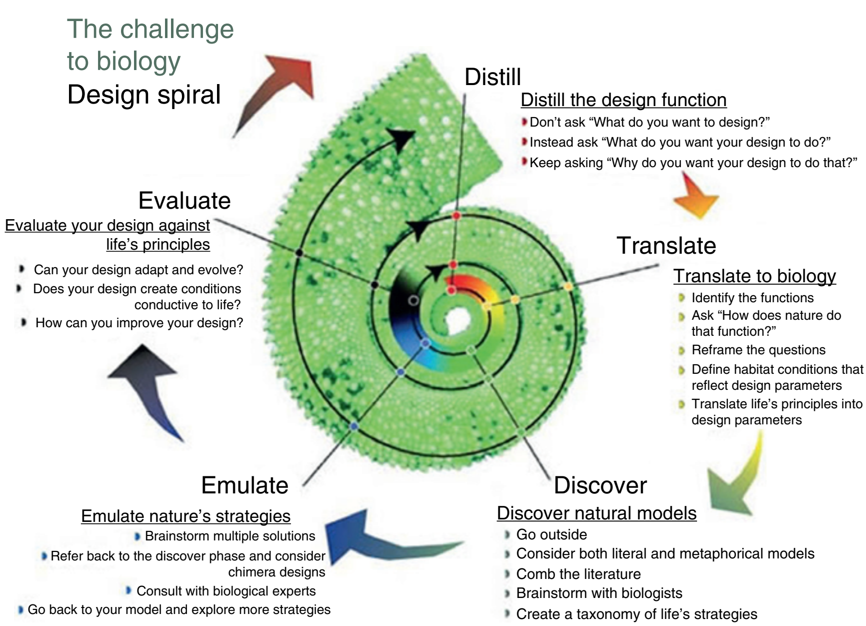

Figure 1.2 How to use reverse biomimicry in product design. *Source:* Reproduced courtesy of the Biomimicry Institute.

1.1 Early Attempts at Biomimicry: The Influence of Birds on the Development of Aircraft

The earliest recorded attempts at biomimicry relate to manned flight. The ninth century poet Abbas ibn Firnas and the eleventh century monk Eilmer of Malmesbury attempted to fly by flapping wings that were attached to their arms. In 1485, Leonardo da Vinci began to study the flight of birds. He realized that humans are too heavy, and not strong enough, to fly using wings attached to their arms. He drew sketches of an ornithopter – an aircraft that flies by flapping its wings. The drawings show an aviator lying on a plank of wood and working two large membranous wings using hand levers, foot pedals, and a system of pulleys. There is no record of da Vinci constructing and testing such a device but, in 1841, a man called Manojlo did just that. He took off from the roof of the Dumrukhana (Import Tax Office) in Belgrade and fortuitously survived as he landed in a heap of snow. We will return to the concept of ornithopters in Chapter 2.

The first person to make well-documented, repeated, successful flights was Otto Lilienthal. A German pioneer of aviation, he became known as the 'flying man'. Initially he tried, like others before him, to fly by flapping wings he had strapped to his arms. After training as an engineer, he began to study the flight of birds, especially storks, and described the aerodynamics of their wings. Based on this research on bird flight, he developed a glider in which he could change the centre of gravity by shifting his body, much as hang gliders do today. Unfortunately, his gliders were difficult to manoeuvre and tended to pitch down, leading to loss of flight. One reason for this was that he held the glider by his shoulders rather than hanging from it like a modern hang glider. Only his legs and lower body could be moved and this limited the amount of weight shift that could be achieved. Nevertheless, in 1893 he achieved flight distances of up to 820 feet (250 m). He had a total flying time of five hours by the time he died in a gliding crash in 1896.

Across the Atlantic in Dayton, Ohio (USA), brothers Orville and Wilbur Wright were reading about the exploits of Otto Lilienthal and his flights in gliders. They later said that Lilienthal's death was the catalyst for their own work on manned flight. Soon they were reading everything they could find about aeronautics, including the work of the 'father of aviation', Sir George Cayley. Cayley identified the four forces that act on a heavier-than-air flying vehicle: weight, lift, drag, and thrust. Modern aeroplane design is based on these discoveries and on the importance of having a curvature of the upper surface of the wings (Chapter 2, Some basic fluid dynamics box). In 1799, long before Lilienthal, Caley may have designed the first glider to carry a human aloft but this has not been verified.

One advantage the Wright brothers had over their predecessors who were attempting flight was the recent invention of the internal combustion engine. This could be used to generate the thrust that was clearly not possible using flapping wings. Despite Lilienthal's fate, the Wright brothers practised gliding so they could master the art of control before attempting motor-driven flight. They realized that Lilienthal's use of shifting body weight to change direction was inadequate. Wilbur had spent a lot of time observing birds and he noted that they changed the angle of the ends of their wings to make their bodies turn left or right. The brothers puzzled over how this could be achieved and eventually came up with wing distortion or 'wing-warping'. In July 1899 the concept of wing warping was put to the test in a biplane kite with a five-foot wingspan. When the wings were twisted in opposite directions, the unequal lift made the kite turn in the direction of the lower end.

Two further modifications were made to the early gliders. To protect the pilot from a nosedive and crash like the one that killed Lilienthal, the Wright brothers mounted an elevator at the front of the glider. By moving the elevator, they could make the craft go up or down as they wished. In early flights, they noticed that wing warping created a differential drag at the wingtips. Greater lift at one end of the wing also increased drag. This slowed that end of the wing, making the glider swivel so that the nose pointed away from the turn ('yawing'). This was corrected by adding a rear rudder. Once they had mastered flying in their gliders, the Wright brothers added engine-powered propellers and made the first ever powered, manned flight in December 1903.

In mid-1910, the Wright brothers made a further change to the design of their aeroplanes. They moved the horizontal elevator from the front to the back because this made the aeroplane easier to control. Control became increasingly important as higher speeds grew more common. The Wright brothers found out about elevators and their optimum positioning by trial and error. Similarly, they mounted the rudder on a tailfin. Had they studied whales or dolphins in the same way as they had studied birds in flight, then they might have reached the optimum design sooner. Both animals have a dorsal fin that acts as a stabilizer or rudder and they move up or down in the water by means of their tails or flukes.

1.2 The Fathers of Modern Biomimetics: Percy Shaw and George de Mestral

Ask 1000 people in the UK what Percy Shaw invented and it is likely that none of them will know. This is somewhat surprising given that his invention of the reflective road studs, more commonly known as 'catseyes™', has saved the lives of thousands of road users by lighting the way along roads in the dark. There are several stories about how he came up with the idea. The most relevant in the context of biomimicry may be apocryphal but it perfectly illustrates the principle of copying function from nature. It involves a drive that Shaw did one night in 1934 along a very dangerous road in Yorkshire that had a very steep drop on one side. At one point he would have driven off the road if it were not for a cat sitting on a fence. The eyes of the cat reflected his headlights and he was able to take corrective action. Soon he had set up a company called Reflecting Roadstuds Ltd and sales of his products took off during the blackout enforced during the Second World War.

There are other versions of how Shaw came up with the idea of 'catseyes' and some of them have no relation to biomimetics. However, an early commercial product that truly was inspired by nature is the hook and loop fastener. The inventor was the Swiss engineer George de Mestral. In 1941, he had been out hunting with his dog Milka and on his return home noted that burdock burrs (seeds) had stuck to his clothes and the fur of the dog. Curious about the attachment mechanism, he examined the burrs using a microscope and noted that they were covered with hundreds of tiny hooks (Figure 1.3). A burr is spherical to maximize the angles by which it might attach to a passing animal and thus be dispersed. What de Mestral conceived was a linear piece of material with hooks that would stick to any rough material. That is, a simple fastener that, unlike a zip fastener or 'hooks and eyes',

Figure 1.3 Close-up photo of a burr showing the microscopic hooks. *Source:* https://commons.wikimedia.org/wiki/File:Bur_Macro_BlackBg.jpg.

did not require two surfaces to be lined up precisely. Subsequently he modified his fastener concept so that one surface had the hooks and the other surface had the loops with which the hooks would engage.

Like many inventors before and after him, de Mestral discovered that turning his idea into reality was much more difficult than he at first realized. Initially he went to Lyon (France) where a weaver made him cotton strips with hooks and loops. These worked as he envisaged but cotton is soft and the fastener wore out quickly with repeated use. So, de Mestral decided to try nylon, a tough synthetic fibre that had been invented in 1937. He found that nylon thread, when woven in loops and heat-treated, retains its shape and is resilient but he still need to create the hooks. He was about to abandon his invention when he came up with the solution: he trimmed the top off the loops with a pair of shears, thus creating hooks that would match up perfectly with the loops (Figure 1.4). But de Mestral's problems were not over because he had to find a way of mechanizing the manufacturing process. That took until 1951, 10 years after he first conceived of 'Velcro'[1], as he called his hook and loop fasteners.

Once the problem of mass manufacturing Velcro had been solved, de Mestral expected that there would be a high demand for his 'zipperless zipper'. It was not to be. Early versions of the product looked like they had been manufactured from left-over bits of cheap fabric and so were of little interest to clothing manufacturers. It was the 1960s before there was a commercial breakthrough: Velcro was used to help astronauts manoeuvre in and out of bulky spacesuits. This was followed by its use in ski clothing, which can also be bulky, and then in diving gear. Today, the use of hook and loop fasteners is widespread.

The story of Velcro illustrates perfectly the different stages in developing a new product from concept to commercialization. First, one must show the feasibility of the concept, and

Figure 1.4 The structure of hook and loop fasteners.

for Velcro this was achieved with the early cotton versions. Next, it is necessary to show practicability: can a version be made that functions reliably and reproducibly? The nylon versions of Velcro did this. Finally, it should be possible to develop a reproducible and cost-effective manufacturing process. For de Mestral, this turned out to be the hardest part of the development process. What might not be realized is that de Mestral was a pioneer in new product development and it is not surprising that it took 10 years to get Velcro ready for the market. Today, most product development is carried out by companies and not by individuals, there is a wealth of literature on the subject, and also specialist consultancies to provide help.

De Mestral was disappointed by the initial lack of demand for his revolutionary new product and this problem still haunts inventors today. Essentially, he had a solution in search of a problem because his product did not fit the needs of his perceived market (fashion clothing). Once feasibility has been established, the smart inventor will undertake market research to establish the real needs of the marketplace and then develop a version of the product that meets these needs. But, de Mestral was a pioneer who cannot be criticized for what he did given the period when he carried out his development and the fact that he did it as an individual.

Relevant Innovations Described in Other Chapters

The new generation of ornithopters (Chapter 2, Section 2.11).

Note

1 Velcro is a portmanteau of the French words velours (velvet) and crochet (hook). The name Velcro is covered by trademarks and should only be applied to material manufactured and sold by the Velcro Company. Similar materials made by other companies should be called hook and loop fasteners but in the minds of the public they are synonymous with Velcro.

Suggested Reading

Khan, A. (2017). *Adapt: How We Can Learn from Nature's Strangest Inventions*. London: Atlantic Books. This title is scientifically incorrect. Nature does not invent things, for invention requires conscious thought, but generates them through evolution and selection.

Müller, R., Abaid, N., Boreyko, J.B. et al. (2018). Biodiversifying bioinspiration. *Bioinspiration and Biomimetics* https://doi.org/10.1088/1748-3190/aac96a.

Whitesides, G.M. (2015). Bioinspiration: something for everyone. *Interface Focus* https://doi.org/10.1098/rsfs.2015.0031.