Biomimicry – a nature-based approach to designing sustainable futures

Richard Dawson and Lewis Winks

Abstract This article introduces biomimicry as an approach to STEM learning with a strong real-world application. It provides an introduction to biomimicry itself and some of the key principles behind using biomimicry as an approach to design. It draws upon almost three years of work within the BioLearn project, which is working with secondary schools in five countries to bring biomimicry into the school curriculum. Piloting in schools is demonstrating that using biomimicry can enhance the teaching of STEM subjects and provide strong links with sustainability issues and future careers.

As we write this, at the end of October, the weather is turning colder. Have a look outside. Have you noticed that the leaves have turned brown and are starting to fall? Did you see the squirrel collect nuts from the beech tree? It makes you wonder: 'How did the tree grow those nuts and how does it know it is time to shed its leaves?' The more you look, the more questions start coming. Nature has evolved over 3.8 billion years into a model of sustainability. Nature recycles waste efficiently, uses renewable power from the Sun, is resilient to sudden changes, is adaptable over time to new conditions and self-regulates through feedback. What if we could use the operating principles found within nature to rethink how we live as humans, to flourish without damaging the natural ecosystems we depend upon for our survival?

Nature-inspired learning takes us on a journey to discover the principles that make nature a model for sustainability. It offers an opportunity to explore how these principles can help tackle some of the greatest challenges facing humanity today such as climate change and increasing levels of waste and pollution. And it empowers students to apply their new competences to create real solutions that work. Nature-inspired education is uniquely valuable in teaching practice because of its dramatic potential to engage students' interests and generate excitement based on real-world examples. No subject can be taught successfully if it does not generate sufficient student interest. Because student interest is a prerequisite to learning, teacher pedagogies must be evaluated with this all-important criterion in mind. Fortunately, nature-inspired education has a track record of success in generating student interest, as well as a strong theoretical foundation to explain its merit.

Let us look at some brief descriptions of nature-inspired approaches to education, as proposed by BioLearn (Stier, 2021: 6):

- A teacher exploring the scientific method has students observe natural phenomena outside the classroom over a period of time, preparing questions about features students notice about nature and what functions these features might serve (e.g. Why do squirrels have big, bushy tails? Why are tree branches often crooked? Why do leaves change colour?). Students then choose one question and design an experiment and test a hypothesis about that feature's possible functional role.
- A physics class learning about atomic interactions reads research papers about how geckos scale smooth glass using van der Waals forces.
- Students exploring climate change solutions in an after-school chemistry club make carbon-negative cement out of car exhaust fumes, based on a chemical process that corals use to build their stony reefs.
- Students in a maker lab create prototypes of car exhaust pipes that remove outgoing pollutants, whose design is based on the students' research into how marine sponges filter food out of seawater and other biological strategies for filtering.
- A teacher exploring the material science and structural engineering concepts of stress and strain has students examine a tree in the school grounds for clues as to how it withstands the passing breeze, despite its massive canopy.
- A teacher exploring the mathematical ideas of volume and mass has students look up from their desks, textbooks, and chalk/white/smart boards, and look out through the window or go outside to determine how to weigh a cloud passing over the school.

These examples share some common patterns. First, in each instance a standard academic idea is being explored (hypothesis testing, volume, mass, stress, strain, electrostatic charge, innovation, etc.). That is to say, nature-inspired education does not require new academic content to be added to curricula. Nature-inspired education is not a subject area in and of itself. It does not add to the burden of existing curricula by adding on more content to the school day. It is a pedagogical approach. Instead of adding to the curricular content, existing academic ideas are explored in less-abstracted and more-meaningful contexts that help engage students' interest and build their contact with and appreciation for the subject under study, as well as with the natural world. In nature-inspired education, existing academic ideas can be addressed without lengthening the school day. Standard school topics are simply explored conceptually in connection with the natural world, using a scientific methodology for asking and exploring questions and, crucially, provoking curiosity.

Second, a wide variety of academic ideas and subjects can be approached through nature-inspired educational approaches. Many of the academic subjects, such as art, science, maths, chemistry, physics and engineering have been developed historically as a direct result of humankind's observation of natural phenomena. From the night sky and Galileo's ideas of mass and motion, to human anatomy and Leonardo da Vinci's artistic realism, the natural world has driven human thought, understanding and creativity. It is thus relatively easy, and completely logical, to teach these subjects and connect their respective academic concepts to the natural world that inspired the development of these subjects in the first place.

A third thing to notice is that the academic ideas and subjects are explored in connection with the engaging context of the natural world. But note that this does not require students to go on expensive and rare field trips to natural or semi-natural areas. It does not even require that students leave the classroom. All academic ideas and subjects explored through a nature-inspired approach can be addressed within the four walls of a classroom (especially with the rich image, video and sound media available to teachers today). That said, when possible, direct contact with the natural world is ideally used to explore topics, both in the school grounds and by leveraging students' experiences as they travel to/from school and around their homes.

Biomimicry – nature as design

Biomimicry (meaning 'to copy life') takes us on a journey to discover the principles that make nature a model for sustainability (Box 1; Benyus, 1997) – a model that achieves dynamic balance, sustains the whole and provides the conditions for survival. Biomimicry offers a design process to apply these principles to address human challenges and to seek solutions that are sustainable and enable humans to thrive within the natural systems we are dependent upon.

Biomimicry has been defined as '*learning from and then emulating nature's forms, processes and ecosystems to create more sustainable designs*' (Biomimicry 3.8; https://biomimicry.net/what-is-biomimicry). It does this based on three intertwined values (Dawson and Winks, 2020):

1. **Emulate** – observe nature closely and we can see how organisms use a vast array of strategies to provision their needs; these strategies are being emulated by many companies in product design. Emulation occurs when we tackle human problems through the inspiration of nature and minimise our impact on the Earth.
2. **Reconnect** – learning from nature requires deep curiosity and observation, reconnecting to the natural world at a level beyond mere utilitarianism. It is about regaining the recognition that we are a part of nature and the relationship of humans as part of nature is essential for our survival.
3. **Ethos** – understanding how we are an integral part of nature, and how nature brings about balance and harmony, we choose how to apply biomimicry thinking with an ethos of care and empathy with all life. It signals the intention to proceed only in ways that work alongside natural balance.

When these values are taken together, biomimicry offers a different way of seeing nature and supports a shift in view of learning about nature to learning from nature. It explicitly places the natural world as a source of solutions to human challenge, providing a moral and practical reason for the conservation of the natural world. It facilitates a deeper look at the natural world through which a sense of sacredness can emerge.

As the three values briefly laid out above suggest, biomimicry is not simply taking ideas from nature to create better products to serve human needs. It necessitates a deep observation of how nature works, the interrelationships between organisms and their

Box 1 Nine biomimicry principles (after Benyus, 1997)

- Nature runs on sunlight
- Nature uses only the energy it needs
- Nature fits form to function
- Nature recycles everything
- Nature rewards cooperation
- Nature banks on diversity
- Nature demands local expertise
- Nature curbs excesses from within
- Nature taps the power of limits

environment and an innate sensing of nature's cycles. Biomimicry offers a method to rethink our relationship with nature, rediscovering our place within the natural world, finding balance, harmony and renewal. In this sense, biomimicry can be far more than a neat engineering solution: it can be used to engage learners deeply with the natural world. In this way, biomimicry can itself become a 'natural pedagogy' rather than simply a tool.

Biomimicry offers multiple points into the natural world. It can be entered from a deep ecology point of wholeness and connectivity, broadening out into seeing how nature works and applying nature's principles to address human needs. Or it can be entered from the perspective of an engineering challenge, exploring nature to see how organisms have solved similar challenges, or even to look at the properties of materials and structures and how they can be applied in a variety of situations. In this sense, biomimicry can appeal to a wide range of people regardless of their current views of nature. As a result, biomimicry can help us see beyond the usual events and patterns of our daily lives. It can suspend our usual way of seeing nature, and offers a new mental model to reshape our relationship as a part of nature. Biomimicry provides inspiration to go beyond simply copying nature, and presents learners with opportunities to enrich and broaden their learning beyond facts and into a new relationship with the natural world.

Box 2 Key biomimicry terms

Function: In biomimicry a function refers to an organism's adaptation which helps it survive and thrive. For example, the purpose of bear fur is to keep warm, in technical terms its function is to conserve heat (insulation). Often, 'designs' in nature have more than one function. A leaf can photosynthesise (convert energy from the Sun into sugar) and it can distribute water (through its veins). Human products also have functions; a kettle has the functions to both contain water and heat water (modify its physical state). In brief, a function is 'what it does'.

Strategy: Organisms meet functional needs through biological strategies. This is a characteristic, mechanism or process which performs the function for them. In the bear example, fur is the strategy for delivering insulation. In a kettle, electrical energy is transferred into physical heat which modifies the temperature of water. In brief, a strategy is 'how it does it'.

Variation and classification – a different approach

Take, for example, a traditional unit in GCSE biology on variation and classification. This might start with students identifying the differences between living and non-living things (Movement, Respiration, Sensitivity, Growth, Reproduction, Excretion, Nutrition – MRS GREN). It would then move on to understanding how different species vary and that these variations are inherited or caused by environmental factors; a dichotomous key might then be used to sort organisms into groups based on certain structures or behaviours. How would a biomimicry approach deliver this? (Table 1).

Any tree in the school grounds can provide a focus for using dichotomous keys – identifying different trees or species of invertebrates found on trees. However, thinking beyond simple identification, an apparently instrumental approach to learning about trees can yield a host of questions driven by the curiosity of students. For example, while thinking about classification, students might consider:

- What characteristics give this tree strength?
- What characteristics provide protection?
- What characteristics provide energy?
- How do these characteristics provide functions that enable the tree to thrive?
- How can we use features to identify and classify the tree?

Take this a step further by focusing on one function of trees, such as provision of strength, transportation of

Table 1 A biomimicry approach within curriculum specifications

Specification	School resources	Biomimicry extensions
• Identify differences between living & non-living things (Movement, Respiration, Sensitivity, Growth, Reproduction, Excretion, Nutrition – MRS GREN) • Understand that these variations may be inherited or caused by environmental differences • Observe that members of a species have features in common • Use keys to sort organisms into groups by common features • Appreciate that there are different ways of classifying living things	Compare the characteristics of living things – go outside if fine. Keys resource: Identifying Organisms Video: *Life on Earth*	Build on use of dichotomous key with trees – consider answers to questions: what characteristics provide strength/energy/transport of water, etc? How do trees inspire designers? How do trees MRS GREN? How do non-living things MRS GREN? Can non-living things mimic MRS GREN? Provide a set of images of inventions/designs inspired by trees. Ask students what inspired each of these designs

liquids or the harnessing of energy. Ask how the tree delivers these functions; what strategies does it use? Consider how these strategies might be applied within human design; what opportunities are there to learn from trees?

Biomimicry – bringing science and design together

Within design and technology subjects, students might be required to demonstrate the necessary knowledge, understanding and skills required to undertake iterative design processes and to place this in a real-world context. The short example below illustrates the power of biomimicry to bring different disciplines together:

Provide students with a sycamore or maple seed (or any winged seed). Ask them to spend five minutes looking at their seed and analysing its movement and structure in as much detail as possible using these points as a guide:

- Examine the seed structure in detail.
- Throw it in the air (sensibly).
- Look at how it flies – what allows it to move like this?
- As you are doing this, try to think about why the seed has these features.

Now offer the mini design challenge shown in Box 3.

Box 3 Mini design challenge

We are now going to use the seed to help us solve a design challenge. The purpose of this is to help you to consider how looking to nature's designs can help to prompt you to think and see differently – applying the ingenuity of the seed to a human design problem.

How can the design and function of the seed be copied to help people who are at risk of flooding?

The purpose of this is to get students to consider how looking to nature's designs can help to prompt us to think and see differently – applying the ingenuity of the seed to a human design problem. Students draw their design and label it with functions as observed in the previous activity making use of the nine principles of biomimicry already given out to assess their design. This approach might lead students to ideas about generating energy, similar to an Archimedes screw, or perhaps ways to slow down or redirect the flow of water to minimise flooding risk. In this activity, the simple observation of a natural object becomes inspiration for a real-world solution.

A natural source of innovation

'*Nature is full of solutions looking for problems to solve.*' This quote by Christopher Viney from Heriot-Watt University (Aitken, 2000) sums up the biomimicry view of nature. Trees offer wonderful lessons in building structures that provide strength using minimal materials. Also, trees grow by capturing carbon from the air through photosynthesis rather than mining minerals from the ground as we do. Companies such as Solidia are exploring how making cement can actually remove carbon from the atmosphere rather than release it. Can we start to envisage buildings as net absorbers rather than producers of carbon?

Taking a study of trees further, we can observe the characteristic curvature of the base of older trees. Why might the tree have grown in this way? In strong winds, the forces generated are channelled to the base where tensile stress is greatest. This particular curvature is very effective in reducing the concentration of stress and you will find it at other points in a tree where there are points of join. Throughout its life, a tree adjusts its growth to better distribute mechanical stress (we see this when we

Figure 1 Weaknesses of right angles in human design vs curves in trees; 'Cracked pavement' by Erin Mallinson is licensed under CC BY-NC-SA 2.0; 'Keeler Oak Tree - distance photo, May 2013.jpg' by Msact is licensed under CC BY-SA 3.0

look at cross-sections of felled trees). Another mechanism some tree species use is interlocking root systems with other trees. This has been found to reduce tree damage during hurricanes and architects are now exploring whether buildings can be made hurricane resistant using a series of interlocking 'roots' between them. Taken to the next step, we might then consider how a tree might be able to inform smarter and more efficient human design. Perhaps such asymmetrical growth might inform the way buildings are designed – to increase strength on the side of the prevailing wind while reducing the need for materials on the other. Another related point of learning might come from watching trees sway in the breeze. Is the strength we associate with long-lived and tall specimens related to their immovability or their flexibility?

Compare how a tree addresses the challenge of tensile stress compared with human-built products. As the images in Figure 1 show, right angles concentrate stress and lead to weakness and fracture. This lesson was tragically learned on ships with portholes designed in a square pattern. These designs created weak points, which weakened the ships' integral strength. In high-stress environments such as aeroplane windows, you will now only find cut-out corners.

A final example involves photosynthesis, which both extracts carbon from the air for growth and converts solar energy to chemical energy (D'Augustino, 2015). The function of chloroplasts is to capture photons of light and this is being mimicked using dyes called 'dye-sensitised solar cells' (Stier, 2014). Because they use dyes, they do not rely on purified silicon and can be made from recycled plastic. Additionally, leaves have tiny wrinkles and folds that allow for maximum light absorption (Kim *et al.*, 2012). Solar panels are typically flat, which means they absorb little of the longest wavelengths. It turns out that the wrinkles and folds in a leaf absorb these far more effectively. Dye-sensitised solar cells made from recycled plastic could both remove silicon and enable a surface structure that mimics leaves, leading to a potential 600% increase in light absorption.

Box 4 About the BioLearn project

The BioLearn project helps young people think about what sort of future they would like to live in. How can they contribute to that future? Can it become reality? BioLearn is about rethinking the future, a future that is already happening because many companies are already fascinated by nature and are innovative enough to create 'bio-inspired design'. See more at www.biolearn.eu/united-kingdom. BioLearn is managed in the UK by Wild Awake (www.wild-awake.org).

In conclusion

By attending closely to nature, we are able to learn the forms, patterns and processes that nature applies to be sustainable. We are able to discover a chain of insight and imagination that begins with identification and ends with creative application of natural principles to solve human challenges. The above examples illustrate the ways in which learning about nature can also become learning with nature, and furthermore can offer real-world opportunities to enhance problem-solving. While on the face of it biomimicry is inherently knowledge based, it also offers important avenues for creative exploration of the natural world. Taking the step from considering the function of natural phenomena to an examination of the strategies nature uses to achieve such functions deepens student knowledge and indeed enhances wonder and appreciation of nature. Yet one of the most important benefits of a biomimicry approach to learning is the application of these strategies to complex human challenges. For this to occur, the learning has to take a creative direction and students must be able to play with their ideas – adapting, changing and learning to accept failure as an aspect of evolution and improvement rather than an end in itself. From this point of view, biomimicry has much to offer – from deepening knowledge of the natural world, to divergent thinking and problem-solving rooted in exploration and creativity.

As part of the BioLearn project we have created a series of modules and lesson plans designed to link closely with the requirements of STEM-based subjects. We encourage you to take a look at, adapt and play with these ideas.

References

Aitken, R. (2000) Snail slime 'could mend bones', *BBC News*. Available at: http://news.bbc.co.uk/1/hi/health/900869.stm.

Benyus, J. (1997) *Biomimicry – Innovation Inspired by Nature*. New York: Harper Collins Publishers.

D'Augustino, T. (2015) Where do trees get their mass from? Michigan State University. Available at: www.canr.msu.edu/news/where_do_trees_get_their_mass_from.

Dawson R. and Winks L. (2020) Exploring biomimicry. Blog piece for National Association for Environmental Education. Available at: naee.org.uk/exploring-biomimicry.

Kim J., Kim P., Pégard, N., Oh, S., Kagan, C., Fleischer, J., Stone, H. and Loo, Y. (2012) Wrinkles and deep folds as photonic structures in photovoltaics. *Nature Photonics*, **6**(5), 327–332.

Stier, S. (2014) *Engineering Design Inspired by Nature*. The Center for Learning with Nature.

Stier, S. (2021) Introduction to nature-based design. BioLearn. Available at: www.biolearn.eu/wp-content/uploads/2019/10/background-article-.pdf.

Richard Dawson is Director of Wild Awake. Email: richard@wild-awake.org
Lewis Winks is BioLearn Project Officer, Wild Awake and Lestari. Email: lewis@lestari.org