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Biomimicry Basics and Mentors

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CHAPTER 23

Biomimicry Basics and Mentors

Jeremy Faludi

Goals

- Ideate sustainability solutions using inspiration from nature
- Find inspiration from biological mentors

Why It Matters

Many sustainability problems require creative out-of-the-box thinking. Nature is a great source of such ideas, because (1) it designs very differently from modern industry, (2) it contains a vast variety of design strategies, and (3) it is the very world we are trying to emulate and harmonize with when we practice sustainable design. Thus, biomimicry can be a powerful ideation tool, can inspire us, and can change our relationship with nature.

Summary

- To design products and systems in harmony with nature, we can look to nature's designs.
- For inspiration from mentors:
 - Define the problem biologically.
 - Find mentor organisms and their strategies, either through direct observation or online/literature sources.
 - Translate biological strategies into buildable things.

23.1 Biomimicry: Inspiration from Nature

Biomimicry (also called bionics or bio-inspired design) is a form of design-by-analogy to find innovation inspiration from nature. It isn't automatically sustainable—historically, it is most often used for robotics and medical devices—but it can be excellent for out-of-the-box thinking, and can remind us we are part of nature, responsible for healthy contributions to the ecosystems we live in. It can especially inspire us to have a relationship with nature as mentor and family, rather than simply as resource extraction site and waste dump. To redesign products and systems in harmony with nature, shouldn't we understand how to design like nature? Of course, nature does not intentionally design anything—all life is evolved. But just as physicists create equations to describe “laws” of nature, we describe “design strategies” of nature to translate them into our language and bring analogous strategies into our designs. That is the heart of biomimicry.

Biomimicry can work at any scale, from the microscopic structure of waterproof fabric inspired by lotus leaves to a ten-story building's passive ventilation cooling inspired by a termite mound.

Figure 23.1 shows Amphico's waterproof yet breathable clothing inspired by arthropod exoskeletons. Rather than using multiple layers of different materials, some of which are toxic PFAS chemicals, it uses a single polymer which is non-polar and woven into threads with nanoscale and microscale pillars, giving water very little surface area to stick to. The combination of material and geometry makes their fabrics



Figure 23.1 Amphitex waterproof and recyclable mono-material fabric (left) and the lotus leaves that inspired them (right)

Source: Amphico.com and Unsplash.

superhydrophobic, and as water beads up and runs off, it also carries away most dirt, which saves washing energy and chemicals. Because the material is all one polymer, rather than layers of different ones, it can be easily recycled.

Zimbabwe's Eastgate shopping center (Figure 23.2) imitated a termite mound's

ventilation tunnels for passive cooling. It uses 50% less air conditioning energy (3% less total energy), and even reduced air conditioning installation costs by 90% because so little mechanical equipment was required. It's also more resilient to power outages, because it works passively. Interestingly, scientists later found that termite mounds do not work the way they were

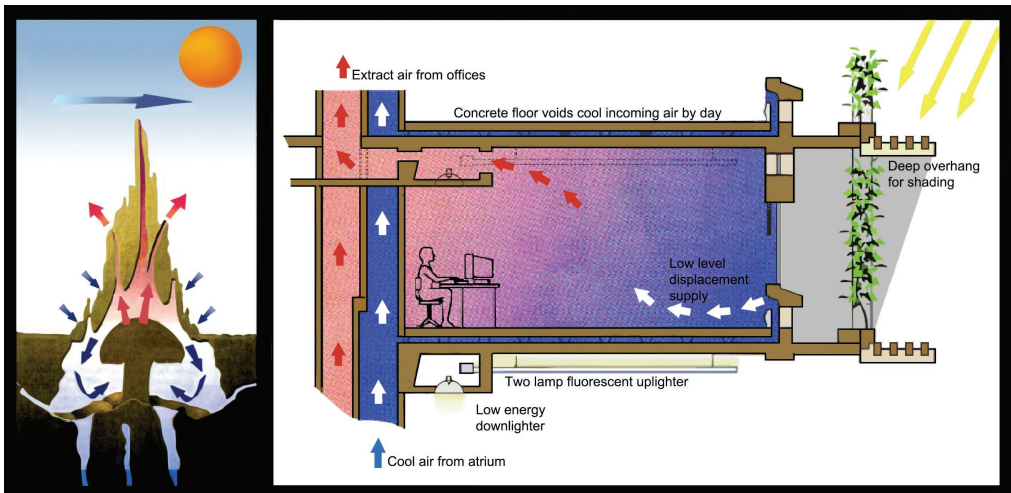


Figure 23.2 Eastgate Centre in Harare, Zimbabwe, was inspired by a termite mound's passive ventilation

Source: Mick Pearce.



Figure 23.3 Aesthetics and slavish imitation are not meaningful biomimicry

Source: Wikimedia commons.

believed to when Eastgate was designed, but the building design is still effective. This illustrates how biomimicry is not slavish imitation, it does not need to be completely accurate to provide inspiration for innovation.

Sustainable biomimicry isn't about aesthetics or slavish imitation of nature, it's about using nature's functional principles. A building that looks like a duck might be fun (see Figure 23.3), but if there's no useful duck-inspired function that measurably improves environmental impacts, the inspiration is shallow. The fabric in Figure 23.1 looks nothing like arthropod exoskeletons, nor does Figure 23.2 look like a termite mound. But they imitate their functions to provide sustainability benefits.

23.2 Biomimicry Levels and Roles

Janine Benyus's (1997) book, *Biomimicry*, explains that bio-inspired design can be applied at different levels: **form**, **process**, or **system**. For instance, Lotusan paint is biomimetic on the level of form, because it imitates the physical form of the lotus leaf (on the micro-scale). But it's not biomimetic on the level of process because the paint isn't manufactured by planting seeds and waiting for them to grow. Lotusan paint is also not biomimetic at the system level—at the end of its life, the paint is not recovered for use on other buildings. In nature, all waste becomes food for some other organism—that is what inspired Cradle to Cradle's concepts of

technical and biological nutrients. A product doesn't have to be biomimetic on all three levels to be more sustainable than normal products; a great improvement on one level can be enough. Such improvement is best measured by LCA or other quantitative scorecards.

For example, Cypris Materials paint is biomimetic in both form and process (Figure 23.4). In form, its colors come not from pigment, but from structural color, like Morpho butterfly wings or the irises of blue-eyed and green-eyed people. The paint is a clear polymer with nanoscale ridges; different sizes reflect different wavelengths of light, for different colors. This eliminates the wide variety of chemicals and heavy metals traditionally used for paints. In process, it's



Figure 23.4 Cypris Materials paints eliminate many of the toxic chemicals in paints by replacing pigments with structural color, inspired by butterfly wings

Source: Cypris Materials, Ryan Pearson.

biomimetic because rather than using heat, energy, or nanoscale machinery to build it, it uses chemistry to self-assemble at ambient temperature, like butterfly wings.

Note the difference between biomimicry and biomaterials. A table built of wood is “bioutilization” but might not be biomimetic. Its form, manufacturing process, and system might have nothing to do with nature. But combining biomimicry and biomaterials is often a great strategy. For example, Ecovative packaging materials (Figure 23.5) replace styrofoam with mycelium, which means they use biomaterials, plus their manufacturing process is mycelium growth produced using agricultural waste feedstock, and they can be composted at end of life. Thus their process and system are biomimetic, in fact literally being a biological cycle.

Benyus's book also points out that biomimicry can play multiple roles. “Nature as model” means nature's role is a source of inspiration, but it also can also play the roles of “nature as measure” and “nature as mentor.” Nature as measure means changing our metrics for success from weak goals like 10% less energy or 20% recycled material



Figure 23.5 Mycelium packaging is both biomimetic and bioutilization

Source: Grown Bio.

to truly sustainable goals, performing like an organism in a healthy ecosystem. That means 100% circular material flows running on 100% clean renewable energy and contributing positively to the surrounding web of life with rich diversity. How would your product and production have to change to accomplish that? Finally, nature as mentor means changing our relationship with nature, as mentioned before, to treat the Earth and all its organisms as teachers to respect, learn from, and give back to.

23.3 Limitations of Biomimicry

Biomimicry's strengths are the inspiration it gives for creative novel solutions and connection with nature but like all tools and paradigms, it has its limits. First, it does not provide quantitative metrics for environmental or social impact; its principles for how nature works can provide inspiration for creating such metrics, but those must be validated on their own. Its creative solutions may not be sustainability improvements. Thus, biomimicry is not as useful for setting design priorities, benchmarks, or success thresholds as LCA or eco-certifications. In addition, biomimicry from mentors has the difficulty of bridging the gap between biological strategies and what current industry can build today. Biomimicry from principles usually circumvents this, but is often less inspiring because it lacks direct connection with natural mentors. However, these limitations can often be overcome by combining biomimicry with other sustainable design and engineering methods.

23.4 Where to Use Biomimicry

Combining biomimicry with other methods makes it more powerful and reliable. As mentioned above, it is an excellent ideation tool, but needs guidance to ensure its ideas are both practical and sustainable. Thus, it should be used after other design methods have established goals and metrics for success, and before gatekeeping steps to compare winning ideas for further development. For example, in Whole System Mapping, biomimicry should be used in the brainstorm step, after the system map is drawn and LCA has set design priorities, but before LCA is used again to evaluate new ideas. For another example, in using Cradle to Cradle, biomimicry is already the source of the Waste = Food principle, and can help suggest more specific target visions such as the Mannahatta Project's list of ecosystem services New York City should provide (Sanderson, 2013). By using biomimicry well, combined with other methods, we can find countless creative ideas and listen better to nature.

23.5 Doing Biomimicry

There are many ways to find inspiration in nature. Like most design, some methods push a new technology, while others are demand-driven. For biomimicry, the technology push starts with a well-understood organism and a lab that has successfully built something imitating the organism's strategy for some function, like the surface structure of a lotus flower. Then designers search for product applications for a good cause, like

self-cleaning surfaces that avoid cleaning chemicals and water overconsumption. Its advantage is that it eliminates the main obstacle of other biomimicry methods: translating biologically-inspired strategies into buildable things. Its disadvantage is that it's limited to pre-existing solutions.

Most sustainable designers use demand-driven biomimicry: they identify a problem to solve, then seek inspiration from the natural world. The main hurdle here is translating nature's strategies to things you can build today in industry—it took the inventor of Velcro ten years to work out viable manufacturing processes and materials. Today's manufacturing and chemical engineering are advanced in many ways, but they are sorely lacking compared to nature's ability to build from the atomic level upwards, using only sunlight and nontoxic organic chemistry at ambient temperatures and pressures. Nevertheless, this approach is successful enough to be the default for most practitioners, such as the Biomimicry Institute.

The Biomimicry Institute's method is the "DesignLens" (Baumeister, 2013; Biomimicry 3.8, 2013), with eight steps shown in Figure 23.6 (details available online at Biomimicry.net). Other demand-driven methods include Nature Inspired Design (Tempelman et al., 2015), the method by Reap and Bras (Reap & Bras, 2014), and the Biomimicry Institute's earlier Design Spiral.

Here, we'll use a streamlined modular version of the DesignLens that fits better into the limited time of most design practice (Faludi, 2018). This modular version has two to five steps, depending on whether you find biological mentors in real life and learn their



Figure 23.6 The Biomimicry Design Lens method

Source: Biomimicry 3.8 (2013).

strategies yourself, use pre-analyzed data to find biological strategies directly, or use pre-analyzed and pre-abstracted principles of natural design to brainstorm from. See Figure 23.7.

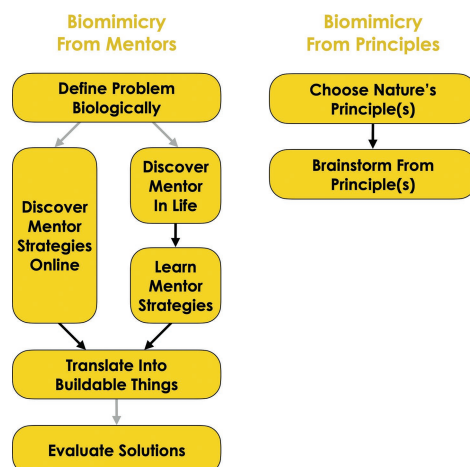


Figure 23.7 The streamlined modular biomimicry method; gray arrows are optional connections, black arrows are necessary

Source: based on Faludi (2018).

Figure 23.7 shows two main ways to do biomimicry: finding inspiration from mentors (left column) or from general principles (right column). The latter will be discussed in Chapter 24; it's fast and easy but doesn't connect you with nature as well. Biomimicry from mentors will be described in this chapter, below. It involves finding specific organisms in the wild or in literature; this is usually more time-intensive and difficult, but more inspiring.

23.6 Doing Biomimicry from Mentors

23.6.1 Define Problem Biologically

To find inspiration from natural mentors, as shown in Figure 23.7, first define your problem biologically. For example, to improve a refrigerator, should your goal be to keep food cool, or to prevent food from decaying by fungus or bacteria, or other? The more concrete you can make your goal, the better; if you feel that narrows your scope too much, you can repeat the process multiple times with other problem definitions.

Once you have a clear function, translate it into a biological analogy. This gives you starting places of where to look in nature. For example, how do animals stay cool in the heat of the desert? How do plants prevent decay by fungus or bacteria in jungle heat and humidity? The problem definitions suggest different answers. Also include the context your product or service is in: indoors or outdoors, wet or dry, large or small, rich or poor, etc. These can help refine your search.

23.6.2 Find Mentors and Strategies

Second, find mentors and their strategies. This is the inspiring part. You can find inspiration by direct observation (usually outside) and/or scientific media (usually online). For direct observation, go and explore nature, whether it's your own backyard or exotic locales. Examine the plants, animals, and other organisms you find, in search of things related to your problem definition. This is usually more inspiring than searching online media, but it requires an extra step: once you've found a mentor, you need to understand what strategy it's using, and how the physics or chemistry works. This is easiest to do with an expert on the local flora and fauna, or expert on the physics or chemistry of the organism, who knows these strategies and how they work.

It can sometimes take large amounts of time and effort (even scientific research) to understand these strategies. For example, the nose of Japan's Shinkansen bullet train (Figure 23.8) imitates the beak of a kingfisher bird to reduce noise from pressure waves in tunnels; separately from that, it also imitates owl feather structures to reduce noise in the rails pulling electricity from overhead wires. It cost Shinkansen engineers many months of both theoretical and empirical research to understand how the shapes of these bird beaks and wings performed, and how to imitate their principles on a train. However, the investment paid off: the redesigned trains not only improved user experience and reduced neighbor complaints, they also reduced energy use by 15% while enabling the train to travel 10% faster (see Figure 23.8).



Figure 23.8 Shinkansen 500 series train, kingfisher's beak, and closeup of owl feathers to show the sound-damping leading edge

Source: Wikimedia Commons by つ, Joefrei, & Mdf.

Instead of direct observation, or in addition to it, you can **find mentor strategies online**. The simplest option is to search the AskNature.org biomimicry database: you can do a keyword search for the function you're looking for, or browse through the taxonomy of functions. AskNature.org not only shows the mentors, but explains how their strategies work in language designers, engineers, and architects understand, so that's no longer an extra step in your process. When a product exists using that strategy, there's also an "innovation: industry" page on that; academic inventions are in "innovation: academia" pages. See Figure 23.9.

If you have more technical biology knowledge or are not afraid of jargon, you can search for mentor strategies in scientific literature

using databases like Science Direct or PubMed. You could also search for examples in physical books; even some non-technical books with quality illustrations can provide good inspiration. See the Resources list at the end of the chapter.

Find as many mentors and strategies as you want, but 5–15 of them give you a good number of options without being overwhelming. When gathering your biological strategies, write them on sticky notes so you can group them or move them around. You'll often find related or redundant ones. That's okay, it may imply the strategy is particularly good. But make sure you have several different strategies, to give yourself choices. When you write or sketch each strategy, also list its mentor organism. If you

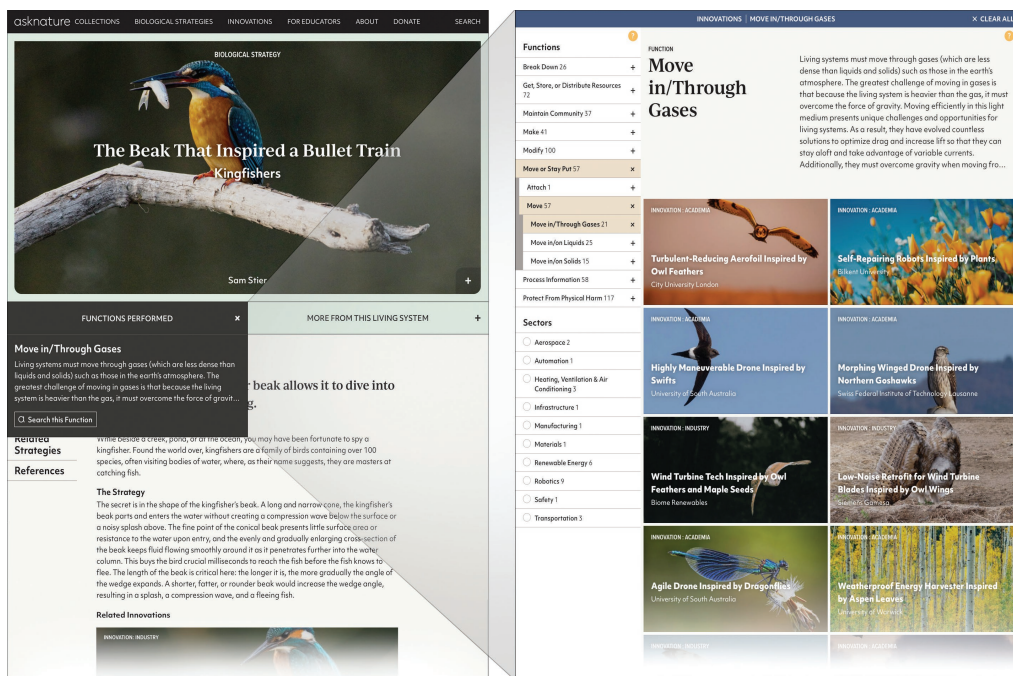


Figure 23.9 The AskNature online database of biomimicry, showing a biological strategy page (left) and a function taxonomy browsing page (right), with links to pages on academic and industry innovations

Source: Unsplash and Wikimedia Commons, Stuart Price & harum.koh.

want, include pictures and notes. It's best to keep a citation or URL for each organism and strategy, in case you need more detail later.

23.6.3 Translate to Buildable Things

Next, translate strategies into buildable things. For every natural strategy in the last step, list one or more ways to produce it with existing technology that's commercially viable for you. Contract manufacturers, organic chemists, and others can help you brainstorm on manufacturability, if needed. Line up all your sticky notes from the last step, and use a new color of sticky note to brainstorm buildable ideas for each strategy, one buildable idea per sticky note, as shown

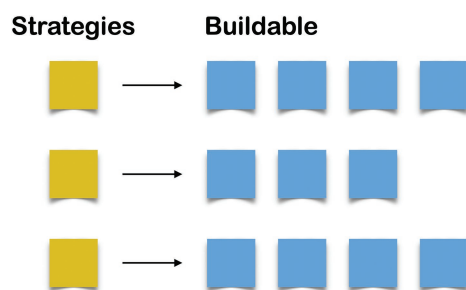


Figure 23.10 Brainstorming how to translate biological strategies into buildable things

in Figure 23.10. Each buildable idea will have limitations, and that's okay. To work around this, have several ideas for each biological strategy, especially ideas relevant to your product's context (e.g., used outside in high wind speeds).

Translating to buildable things is an important step, because nature's best strategies may not be feasible for you to build with today's technology. Therefore, the best strategy for you may not be the best strategy in nature; as long as it's better than what you have, it's still an improvement. Biomimicry is design-by-analogy, and these analogies are usually the hardest part. Velcro is a biomimetic product, imitating how burrs stick to a dog's fur; the principle is very simple, but it took ten years to commercialize, because a new manufacturing method had to be invented. And it's still not biomimetic on the process level, because nobody knows yet how to grow Velcro at ambient temperature with water-based non-toxic chemistry like fur or burrs grow. So don't choose a favorite biological strategy, choose a favorite way to build a strategy.

23.6.4 (Optional) Check Versus Principles

You could finish there, going back into your normal product development cycle. As Figure 23.7 shows, the next step is optional. But you could finish by using biological

principles as quality control. You'll need to do some form of narrowing down to a winning idea (or a few ideas) to move forward with. To narrow down using biological principles, you evaluate your new buildable ideas by how well they align with principles of nature, discussed in Chapter 24. Go through your new buildable ideas one by one, and for each idea, see how many principles it follows well, especially ones relevant to your application. For example, with a bullet train, "use low energy processes" in Figure 24.1 in Chapter 24 is very relevant. This can help you choose your favorite buildable idea(s) to move forward with. If you notice a principle that your new ideas don't follow but should, you might stop and redo previous steps to find new mentors or new buildable ideas. Or you might choose to brainstorm from the natural principle.

This step is optional because LCA, eco-label checklists, and other sustainability measurements are more objective and relevant for design decision-making, but using biological principles can be a nice way of considering insights from previous biomimicry researchers in your design process.

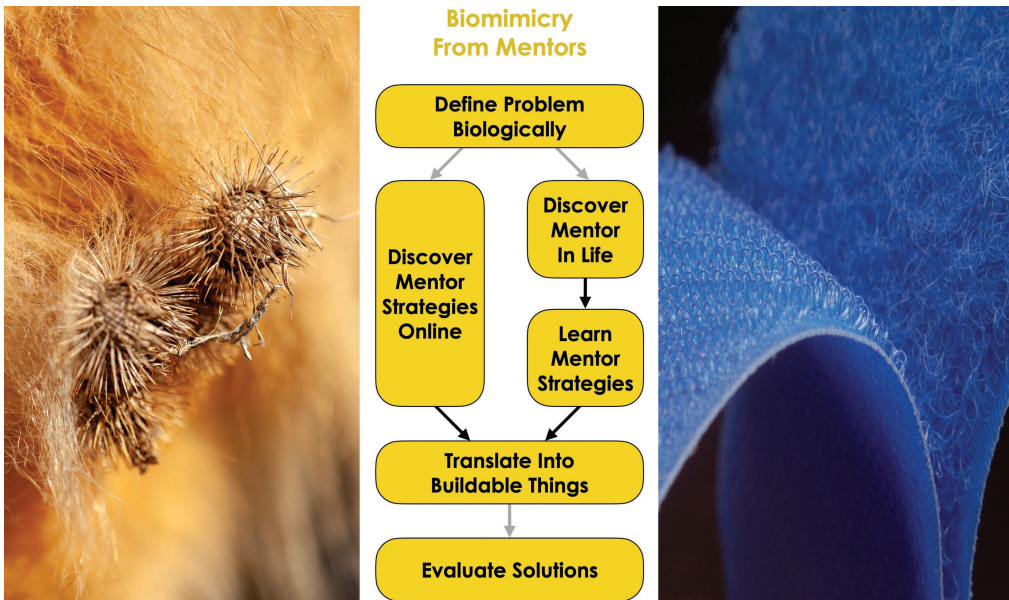
Resources and References

Resources for Further Study

- Observing nature in your own back yard, a nature reserve, park, or botanical garden, etc.
- *Biomimicry*, by Janine Benyus (the book that started the modern biomimicry movement). 1997. William Morrow.
- *Nature Inspired Design*, by Erik Templeman, Bram van der Grinten, Ernst-Jan Mul, Ingrid de Pauw (a practical guide). 2015. Boekengilde.
- *The Way Nature Works*, edited by Robin Rees (a picture book for ideas). 1997. Wiley.
- *Cats' Paws and Catapults*, by Steven Vogel (an excellent source of mechanical engineering-related biomimicry). 2000. W.W. Norton & Company.
- *On Growth and Form*, by D'arcy Thompson (a large tome of theory and a sourcebook of images). 2018. Forgotten Books.
- *Out of Control*, by Kevin Kelly (an inspiring book of systems design theory). 1995. Basic Books.
- *Structural Biomaterials*, by Julian Vincent (a materials science analysis of natural materials). 2012. Princeton University Press.
- *Biomimicry for Optimization, Control and Automation*, by Kevin Passino (a computer science textbook on genetic algorithms, neural networks, etc.). 2005. Springer.
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Velcro was inspired by burrs sticking to fur. It took ten years to go from inspiration to manufacturable product.

Source: Shutterstock and Velcro.com

How to Apply #23: Biomimicry from Mentors

Time Estimate: 70–130 Minutes

Goal: Use inspiration from specific organisms (“mentors”) to ideate solutions to a problem.

STEP 1: Define the Problem Biologically

Time Estimate: 10–20 Minutes

Choose a problem you’d like to solve about your product. Usually it’s best to choose specific mechanism-level problems, but you can also try larger-scale abstract problems. If you’re using biomimicry in your Whole System Mapping brainstorm, the problem can be your system-level priorities (e.g., for a refrigerator, reducing energy impacts without sacrificing cost or user experience) or a more specific problem uncovered in that brainstorm (e.g., prevent heat transfer into the refrigerator when you remove food).

Translate your problem into a biological analogy, as described in the chapter (e.g., for a refrigerator, how do organisms keep cool, or how do they prevent rotting?). Ideally also include the sustainability concern (e.g., not using electricity) or usage context (e.g., in a hot humid environment). This helps you find where to look for mentors: animals in the desert? Plants in the jungle? Others?

STEP 2: Find Mentor Organisms and Their Strategies

Time Estimate: 30–60 Minutes

Find biological mentors and see what strategies they use to solve your problem. Three main sources are direct observation of natural organisms (usually outside), the AskNature.org website, and literature (e.g., books or online scientific journals).

- **Direct observation:** Go outside, to your own backyard or exotic locales, and directly see, hear, touch, etc. When you find an inspiring and relevant aspect of an organism (e.g., the shape of a leaf or the activities of ants), write it down or sketch it. Then try to understand what the physics or chemistry or other basic principle of the strategy is, as described in the chapter, and write or sketch it. You'll often need to search literature for this. Reminder: this is easiest with expert assistance, like a biologist.
- **Online:** Go to the AskNature.org website, and search for your function, or browse through the taxonomy of nature's strategies. It not only shows the mentors, but explains how the strategies work. Write down both the organisms and sketch or write how their strategies work. It's best to keep the URL for each organism and strategy, in case you need more detail later.
- **Literature:** browse the books in the chapter's Resources list, or search academic databases like <https://www.sciencedirect.com> or <https://pubmed.ncbi.nlm.nih.gov> if you have strong technical expertise. Again, write both the organisms and sketch or write how their strategies work, and keep citations or URLs, in case you need more detail later.

Write or sketch the strategies on sticky notes, so you can group them or move them around. Find at least 5–15 strategies. Have at least two or more from AskNature, and one or more from somewhere else, to diversify.

Once you're done collecting strategies, group them by strategy—you'll usually find several overlaps. If several organisms use the same strategy, this is a hint it's a very effective strategy. However, make sure you also have several different strategies, to give yourself choices.

STEP 3: Translate Strategies into Buildable Things

Time Estimate: 20–40 Minutes

Line up all your sticky notes from Step 2 in one column, and use a new color of sticky note to brainstorm rows of buildable ideas for each strategy, as in Figure 23.10. For every natural strategy from Step 2, think of several ways to commercially produce it. Especially think of ideas relevant to your product context. Experts such as contract manufacturers, organic chemists, and others can help you with the ideation.

Draw or briefly describe each buildable idea on its own sticky note. Each idea will have limitations, as discussed in the chapter; having many ideas gives you many options.

STEP 4 (Optional): Using Principles as a Quality Control

Time Estimate: 10–20 Minutes

If you want, you can evaluate how biomimetic your new ideas are, by comparing them to principles from nature, such as Biomimicry 3.8's "Life's Principles" or others listed in the chapter. This can help you choose your favorite idea(s) to move forward with.

Go through your new buildable ideas one by one, and for each idea, see what principles it follows better than the original product did. If you notice a principle that your new ideas don't follow but should, you might stop and redo previous steps to find new mentors or new buildable ideas. Or you might choose to do the exercise on biomimicry from principles.

This step is optional, as most people find LCA, a Whole System Mapping decision matrix, eco-label checklists, or other sustainability measurements to be more objective and targeted, but this can be another way of considering natural principles in your design process. You'll need to do some form of narrowing down to a winning idea (or a few ideas) to move forward with.

Checklist for Self-Assessment

To score your success on this exercise, see if you...

- ☐ *Formulated a clear problem statement.*
- ☐ *Rephrased the problem biologically.*
- ☐ *Found 5+ strategies (2+ strategies from AskNature, 1+ strategies from elsewhere).*
- ☐ *Included mentor organism names (ideally also citations/URLs).*
- ☐ *Sketched or described multiple buildable version(s) of each strategy.*
- ☐ *(Optional) Evaluated winning strategies based on principles of nature.*