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Biomimicry: innovation and design inspired by Nature

BIOS4YOU
AR 2.0

BIO-INSPIRED STEM TOPICS FOR ENGAGING YOUNG GENERATIONS
THANKS TO THE USE OF AUGMENTED REALITY

Project Number: KA220-BW-23-30-126516

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General topic of the learning path	Biomimicry: innovation and design inspired by Nature
Specific name of the learning unit	Bio-Design and Innovation
Target user age	14-18 years
Learner prerequisites	Basic knowledge of Chemistry, Biology, Physics
Description of the learning unit	This unit will guide teachers and students on how they can use nature in a multidisciplinary learning path. AR tools enhance visualization and engagement.
Subject involved	Physics, Chemistry, Biology, Mathematic
Keywords	Biology, Bio-inspired, Biomimicry, Bio-design, Innovation, AR, Visualization, Interactive Learning
Key-skills, abilities, knowledge that can be acquired	Explore nature and its ability to inspire sustainable improvements in our environment, problem-solving, innovative design, AR-based prototyping skills.
Resources and didactic tools used	Research papers, books, scientific databases, webinar results, web-based resources, AR tools (e.g., JigSpace, Assemblr EDU, Merge Cube, CoSpaces Edu).
Evaluation criteria and assessment	Based on the knowledge, abilities, and skills gained during the course, including AR-based assessments such as simulations, prototyping, and feedback.

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Introduction

Bio-inspired design is a relatively new term. More widespread terms are biomimetics and biomimicry. Bio-inspired design has been used to develop innovative technical solutions in almost every engineering field. When the idea of systematically analyzing biological systems emerged in the mid-20th century as bionics, the main focus was on control and communication systems (Keto 1960). Keto (1960) proposed applying bio-inspired control and communication in electronics, aeronautics, and navigation. However, historic examples of bio-inspired design already include further application areas. For example, the aerodynamics of biological systems were frequently regarded as models to conceptualize parachutes or early flying machines (Nachtigall and Wisser 2015, p.6). Modern examples of bio-inspired design are applied in technical fields such as mechanical engineering, architecture, industrial design, software engineering, robotics, medical technology, and so on.

The integration of augmented reality (AR) revolutionizes this process by enabling learners to interact with biological systems in immersive 3D environments. Students can visualize biomimetic processes, simulate real-world applications, and collaborate on innovative projects using AR tools. This blend of technology and nature enhances understanding, creativity, and problem-solving in STEM education.

Despite its high innovation potential, the application of bio-inspired design presents challenges. Significant challenges are disciplinary barriers, i.e., the goals, working approaches, and the fact that the language of biology and technical product development are fundamentally different. Biology is a natural science; it aims to understand living systems. Technical product development, or engineering design, aims to develop technical systems. The difference between the biological goal of understanding and the technical goal of development reflects the different working approaches of biologists and engineers. This clash frequently causes problems in bio-inspired design.

10 Amazing Aspects of Bio-inspired Design	Specification
Abundance of Biological Solutions	Offers a vast pool of possible solutions to technical problems. Digital databases access to the several thousands of biological inspirations.
Optimization	a biological system is optimized, the bio-inspired design is optimized as well.
Synergy Effects and Transdisciplinary	The technical biology is a prerequisite for bio-inspired design
Integration of Material, Shape, and Function	Form follows function: Biological systems often realize functions on multiple scales using both composite material properties and shapes.
Discovery Beyond that Which is Human-like	Many biological solutions with high potential for technical application
Flexibility of Bio-inspired Design	Flexible design approach

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	Wide range area of application Different design methods
Sustainability (or not?)	Environmentally-friendly
Biodiversity	Bio-inspired design can have a positive societal impact
Biologization	Traditional natural sciences beside the technical and engineering disciplines tackle some of the biggest challenges: energy consumption and a sustainable economy
Multifunctionality of Biological Systems	Biological systems have to fulfil multiple functions using limited resources

Table 1. 10 Amazing Aspects of Bio-inspired Design, (Hashemi Farzaneh,2019)

The Biomimicry theoretical framework:

- **Principles of Biomimicry**

The biomimicry principles focus exclusively on nature's attributes, thereby implying that humans have much to learn from the billions of years of the natural world's evolutionary experience.

a- Nature uses only the energy it needs
b- Nature fits form to function
c- Nature recycles everything
d- Nature banks on diversity
e- Nature demands local expertise.

- **Bio Design activities:**

Bio-inspired design methods support different activities:

- Planning
- Abstraction
- Search
- Analysis and Comparison
- Transfer

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Planning a bio-inspired design project and other technical product development projects or planning biological research projects are different from each other. The interdisciplinary nature of bio-inspired design poses a challenge for the design procedure, and there can be different starting points for the project. Moreover, if biologists and engineers collaborate, the integration of their work must be considered. Also, Abstraction is an essential part of bio-inspired design. In fact, designers have to conduct abstraction over and over again throughout a bio-inspired design project: they must abstract a technical task or enable searching for biological inspiration. They must abstract technical and biological systems to make them comparable. They must abstract again to formulate analogies for transfer… and so on. Search, in particular, the search for biological inspiration, is addressed by numerous methods for bio-inspired design. It is a key activity when a bio-inspired design project is started from a purely technical viewpoint (technical task, looking for a biological inspiration) or from a strictly biological view (interesting biological solution, looking for a technical application).

Designers have to analyze and compare both technical and biological systems carefully to apply bio-inspired design successfully. There are numerous examples where bio-inspired designs failed at the prototype stage because the biological solution could not be applied in a technical environment. An example is the attempt of a student's project to mimic the flagella movement of bacteria on a much larger scale. Due to the different influences of fluid forces, the rotational flagella movement could not effectively move liquids. Finally, the transfer of bio-inspired analogies is the core activity of bio-inspired design. All bio-inspired design projects aim at transferring more or less abstract analogies to develop a technical solution.
That said, bio-inspired design projects include, of course, many other activities. However, these activities are not particular to bio-inspired design, as they are also present in other technical product development projects or in biological research projects.

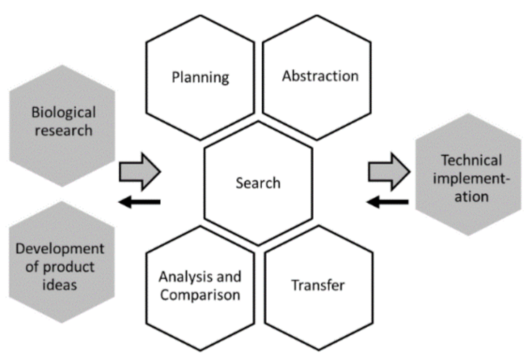

Figure 1. Bio-inspired design: specific and other activities, (Hashemi Farzaneh ,2019)

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- **Bio-inspired Design Approaches**

Even though the majority of bio-inspired design projects and classes focus on the technology pull approach. Some researchers claim that the biology push approach is more innovative. In the case of a technology pull approach, designers start with a technical task. This entails a predefined set of requirements and desired functions. They stick to these boundary conditions, but are relatively free in considering different biological systems. Therefore, they can be more open to transfer several analogies from different biological systems. If a biology push approach is adopted, designers start with a predefined biological system. They might analyze this system in detail, and they are more likely to restrict their analysis to this system instead of searching for other biological systems. However, they are probably more open to searching for multiple technical applications. Moreover, multifunctional biological systems can inspire multifunctional technical systems.

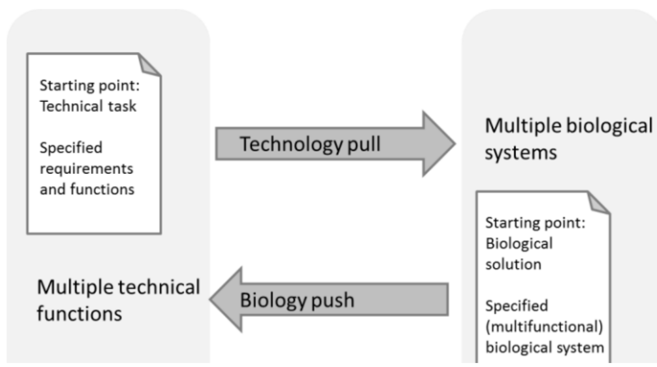

Figure 2. Bio-inspired design approaches: technology pull and biology push, (Hashemi Farzane,2019)

- **Levels of Biomimicry**

There are three levels of biomimicry have to be applied also to design problems. From the biomimetic technologies and techniques, it is obvious and well noticed that there are three levels of mimicry: the organism level, behavior level and ecosystem level. **The organism level** illustrates the mimicking of certain organism or the mimicry of a part from the whole organism, buildings on the organism level mimic a specific organism. **The second level is the mimicry of behavior of which every organism behaves**, buildings mimic how an organism behaves or relates to its larger context. **The third level is the mimicking of the whole ecosystem** and this level is considered the hardest level as it focuses on a functionally very hard issue to mimic, a building mimics the natural process and cycle of the greater environment. Through each level there are five dimension which determine at which extent the mimicry exists. The design is listed as biomimicry in the way it looks like (form), what it is made of (material), how it is made (construction), how it works (process) and what its capability (function). These levels are very important and they complete the biomimicry approaches.
If we want to consciously emulate nature's genius, we need to look at nature differently. In biomimicry, we look at nature as model, measure, and mentor.

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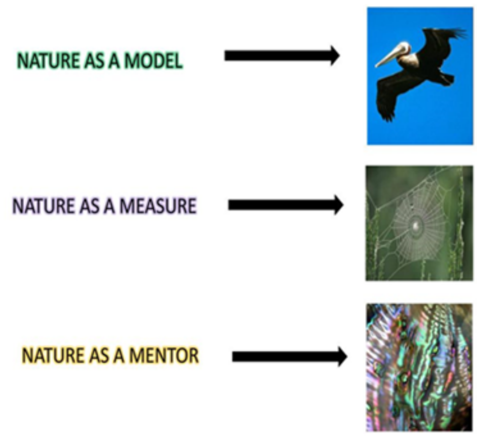
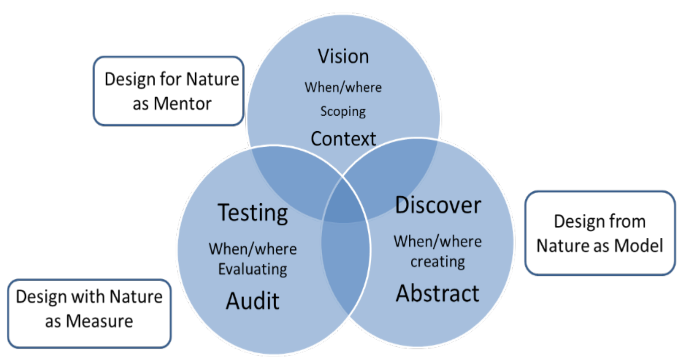


- **Nature as model**: Biomimicry is a new science that studies nature's models and then emulates these forms, process, systems, and strategies to solve human problems – sustainably. The Biomimicry Guild and its collaborators have developed a practical design tool, called the Biomimicry.
- **Nature as measure**: Biomimicry uses an ecological standard to judge the sustainability of our innovations. After 3.8 billion years of evolution, nature has learned what works and what lasts. Nature as measure is captured in Life's Principles and is embedded in the evaluate step of the Biomimicry-Design-Spiral.
- **Nature as mentor**: Biomimicry is a new way of viewing and valuing nature. It introduces an era based not on what we can extract from the natural world, but what we can learn from it.



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How can we apply the biological knowledge?

The application of biological knowledge describes projects with different durations, which are typically conducted from the office desk. In other words, they usually do not entail biological (or technical) experiments or other studies. They usually start with the rough idea of seeking biological inspiration to solve a technical challenge or with the motivation to apply a biological research result for a technical task. The project often requires a more detailed understanding of whether fascinating biological inspirations or technical applications are found. Designers then have to search for additional information. In this scenario, the team aspect plays a minor role, and the designer may be a single engineer or biologist (Hashemi Farzaneh,2019). This means it's better to have a problem-solving process when applying biological knowledge.

Biomimicry as a concept

Biomimicry implies the creative implementation of biological concepts into products. As mentioned in this text, we can provide a broad overview of biomimicry and have described the conversion of physiological and organizational solutions from nature into products and services. Implementation and economic efficiency are shown through selected examples. Four examples of successful implementation of nature solutions. Nature is increasingly being viewed as a model and a benchmark. It is not surprising that during millions of years of evolution nature has created mechanisms and systems that are highly efficient, eschew networks allow professionals from different areas to work together, which is a prerequisite for biomimicry to be successful. Nature entails 'optimizing' rather than 'maximizing', and also it is a model of sustainability since it is a 'closed loop' system. All organisms contribute to recycling Earth's significant nutrients – carbon, hydrogen, oxygen, and nitrogen. If people are to prosper indefinitely, they must act responsibly by imitating nature's closed loop. Biomimicry (gr. bios - life; mimesis - to imitate) is a discipline of applying nature's principles, and it does not only change the ways we think about designing, producing, transporting, and distributing goods and services but also provides opportunities to deal with complex environmental and economic problems.

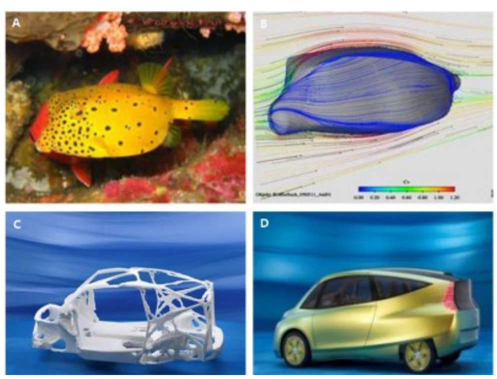

Figure 3. Biomimicry as a concept, (Hwang J &all, 2015)

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What is the method in bio-inspired design?

Having applied bio-inspired design methods, we have noticed that most methods have been developed for specific bio-inspired design scenarios. For other scenarios, they may be less suitable. For example, the Causal Relation Template is a method for formulating a causal relation of a biological system in one sentence and transferring this causal relation to a bio-inspired technical system in another sentence. The technique can help designers quickly transfer several analogies from the biological to the technical domain. However, formulating a biological solution in one sentence requires an enormous simplification. If we have conducted a research project to analyze a biological system in detail, we have probably deduced complex explanations for its strategies.

Formulating a causal relation in one sentence proves less useful to transfer such complex relations. On the other hand, many methods for bio-inspired design require considerable time and training. For example, SBF modeling is a method for abstracting technical and biological systems. The functions of the systems are modeled in detailed steps. This method is very useful for depicting detailed knowledge acquired by literature research or by actual studies or experiments on a biological or technical system. However, in short ideation workshops it is impractical. We have developed three scenarios to indicate the suitability of the methods for certain types of bio-inspired design.

They differ in terms of the effort applied to analyzing technical and biological systems. Your bio-inspired design project might be just between one of the scenarios, or it might be entirely different. Still, these scenarios can give you a hint as to whether a method is worth exploring for your project.
Bio-inspired design incorporates both technical product development and biological research. There is little crossover between commonly used procedures from both disciplines. Moreover, if engineers and biologists are to collaborate, their different working approaches have to be considered to make the common project successful.

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Augmented Reality (AR) in Biomimicry Education

Augmented Reality (AR) superimposes virtual elements onto the real world, creating an interactive and immersive learning environment. In the context of biomimicry education, AR can significantly enhance the understanding of complex biological structures and processes by providing three-dimensional visualizations and interactive simulations.

Studies have demonstrated the effectiveness of AR in educational settings:

- **Enhanced Visualization**: AR facilitates the exploration of intricate biological structures, making abstract concepts more tangible and comprehensible. For instance, AR has been effectively used to visualize macromolecular structures, aiding in the understanding of their functions and interactions (Vardar-Ulu et al., 2024).

- **Embodied Learning:** AR supports embodied cognition by allowing learners to interact with virtual models in a physical space, thereby improving engagement and retention of scientific concepts. This approach has been shown to enhance the learning experience by integrating physical activity with cognitive processing (Mansour et al.,2024).

- **Motivation and Engagement:** The interactive nature of AR has been found to increase student motivation and engagement, leading to more effective learning outcomes. By providing immersive experiences, AR can make learning more enjoyable and stimulating (Subran & Diyana Mahmud, 2024).

Augmented Reality (AR) offers a transformative approach to exploring biomimicry fundamentals by enhancing how learners perceive and interact with biological and technical systems. By providing immersive and interactive experiences, AR facilitates a deeper understanding of biomimicry principles and bio-inspired design processes.

Enhancing Comprehension of Biomimicry Principles through AR

AR enables dynamic representations of biomimicry principles, such as:

- Form-to-Function Fit: Interactive AR models can demonstrate how natural forms evolve to optimize specific functions. For example, AR applications can visualize the microstructure of a lotus leaf, illustrating its water-repellent properties and inspiring self-cleaning surface designs.
- Energy Efficiency: AR simulations can compare energy use in natural processes versus engineered systems, illustrating how organisms like birds achieve flight with minimal energy expenditure. This comparative visualization aids in understanding and applying energy-efficient strategies in design(https://elearningindustry.com/the-role-of-augmented-reality-in-education-revolutionizing-learning-experiences?utm_source=chatgpt.com).

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Visualizing Bio-Inspired Design Processes

The iterative nature of bio-inspired design, from abstraction to analogy transfer, can be challenging for learners. AR mitigates these challenges by:

- **Simulating Biological Processes:** AR visualizations can recreate complex biological mechanisms, such as photosynthesis or the adhesive properties of gecko feet, enabling learners to interactively dissect and analyze these processes.

- **Facilitating Multiscale Analysis:** AR provides a bridge between macro and micro scales, helping users connect ecosystem-level processes to organism-specific adaptations, thereby fostering a holistic understanding of biological systems.

Interdisciplinary Collaboration

AR fosters better collaboration between biologists, engineers, and designers by providing a shared platform for visualizing and discussing abstract biological concepts and their technical applications. It can:

- **Align Differing Terminologies and Perspectives**: AR offers real-time visual references, facilitating communication among interdisciplinary teams.
- **Streamline the Abstraction and Analogy Phases:** By providing interactive models, AR ensures better transfer of biological insights to technical designs, enhancing the efficiency of the design process.

Overcoming Design Challenges

Biomimicry often involves reinterpreting biological strategies for technical applications, a process that requires deep understanding and creativity. AR addresses common challenges, such as:

- **Prototype Failures:** By simulating environmental forces and interactions in AR, users can test the feasibility of bio-inspired designs virtually, reducing costly trial-and-error iterations in the physical world.
- **Dynamic Adaptation:** AR's ability to simulate environmental variability (e.g., light, fluid dynamics) offers insights into how bio-inspired designs might perform under real-world conditions, allowing for necessary adjustments before physical prototyping (Ciloglu & Ustun, 2023).

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Opportunities for AR Integration

AR creates unique learning opportunities in biomimicry education:

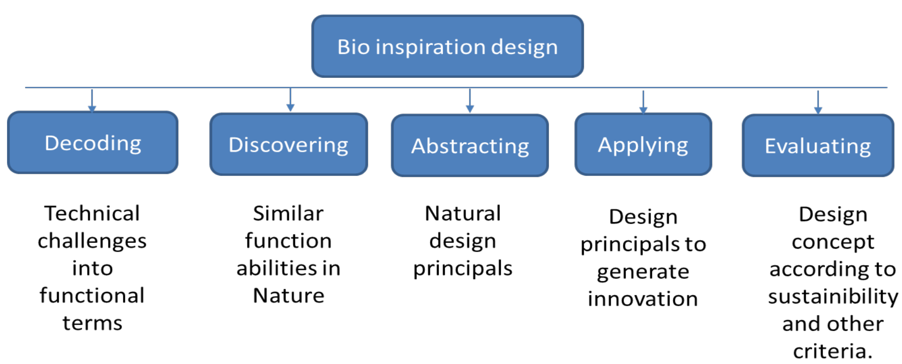
- **Interactive Case Studies:** Learners can explore iconic biomimicry examples (e.g., Velcro inspired by burrs, sharkskin-inspired surfaces) in 3D AR environments, enhancing engagement and understanding.
- **Scenario Testing:** AR can simulate how bio-inspired designs respond to changes in variables like temperature, pressure, or light, fostering a deeper understanding of their applicability and robustness.
- **Real-Time Feedback:** Using AR tools, students can instantly visualize and tweak their bio-inspired concepts, encouraging iterative learning and innovation.

The integration of AR in biomimicry education aligns with broader trends in experiential and immersive learning. As AR technologies become more advanced and accessible, they offer unparalleled opportunities to deepen understanding, enhance collaboration, and inspire innovative applications of biomimicry principles. Embracing AR in educational settings can lead to more effective and engaging learning experiences, preparing students to apply biomimicry concepts in real-world scenarios(https://elearningindustry.com/augmented-reality-in-education-staggering-insight-into-future).

Execute Module:

Bio-inspired design process

Bio-inspired design examines the structure and work of organic frameworks as models and plans or builds modern materials and machines. It is broadly respected as synonymous with biomimicry, bio mimesis, and bio gnosis and comparable to biomimetics. The term biomimetics is inferred from the Greek word bios, "life," and the addition mimetic, "having a fitness for mimicry."



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In general, design inspired from nature could be a strategy for making solutions to human challenges by imitating plans and concepts found in nature. It's utilized all over: buildings, vehicles, and indeed materials.

Bio-Inspired Design Process with Augmented Reality (AR)

The integration of Augmented Reality (AR) into the bio-inspired design process enhances interactivity, visualization, and accessibility. This approach aligns with the concept of "immersive design," which utilizes AR to create realistic digital environments for users. Additionally, the application of AR in design processes has been explored in various studies, highlighting its potential to revolutionize traditional methods (https://journals.open.tudelft.nl/abe/article/view/3753).

Biomimetic Design Practice

Biologists are key players in the biomimicry design process because it relies heavily on biological knowledge; however, the role of the designer remains central. This orientation is particularly true regarding abstracting biological strategies into more broadly applicable design principles and implementing them to solve human challenges. The aim of biomimicry is not to create a replica of a natural form, process, or ecosystem; instead, it is to derive design principles from biology and use them as a stimulus for ideation. A final biomimetic solution should clearly evidence a transfer of functional or organizational principles from biology.

After all, the purpose of biomimicry is to tap the knowledge embodied by nature's 3.8 billion years of research and development, and accomplishing this goal is impossible if the functional analogy between the natural model and the final design is lost in translation.

Biomimetic Design Practice Enhanced with AR

Integrating Augmented Reality (AR) into biomimetic design practices enhances the design process's visualization, simulation, and collaboration aspects, leading to more effective and innovative solutions.

Enhanced Visualization of Biological Models

AR enables designers to explore biological structures in three dimensions, facilitating a deeper understanding of form-to-function relationships. For instance, interactive AR models allow real-time manipulation, aiding in abstracting key principles such as energy efficiency, hydrophobicity, or adhesion. This capability aligns with findings that AR can significantly enhance the design process by providing intuitive and tangible interactions with virtual models (Shin et al.,2013).

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Dynamic Simulations of Natural Processes

Through AR, designers can simulate natural processes like photosynthesis or fluid dynamics within biological structures, observing system functions under various conditions. This dynamic simulation offers insights into transferring biological principles to technical or architectural designs, as AR supports complex data visualization and interaction, crucial for collaborative design tasks (Nilsson et al.,2008).

Strengthened Collaboration and Ideation

AR provides a shared visual platform that enhances interdisciplinary collaboration among biologists, engineers, and designers. Real-time interactions and simulations help align perspectives and terminologies, ensuring a smoother transition from biological principles to technical applications. Research indicates that AR systems can create unique collaborative experiences by allowing users to interact with shared 3D virtual objects, thereby facilitating effective communication and idea exchange (Lukosch, 2015).

Interactive Prototyping and Feedback

Utilizing AR tools, designers can prototype bio-inspired solutions virtually and test them in simulated environments. This approach reduces the cost and time associated with physical prototyping and allows for iterative improvements based on immediate feedback. Studies have shown that AR can support collaborative design sessions effectively, enabling multiple participants to view and interact with AR-enhanced models concurrently (Giunta, 2022).

Investigating Spatial Augmented Reality for Collaborative Design Giunta, L. (Author). 22 Jun 2022

Implementing AR in Biomimetic Solutions

Integrating Augmented Reality (AR) into biomimetic design practices enhances the process by facilitating the abstraction of biological principles, enabling virtual experimentation, and ensuring accurate functional translation into practical applications.

- **Abstracting Principles:** AR allows designers to interact with detailed 3D models of biological systems, aiding in the identification and extraction of functional principles. This immersive interaction enhances understanding and fosters innovation in design.
- **Design Application:** Through virtual experimentation and visualization, AR facilitates the application of abstracted biological principles in real-world scenarios. This approach allows designers to test and refine bio-inspired designs efficiently.
- **Functional Translation:** AR ensures the accurate translation of natural models into final designs by providing tools to dynamically compare and validate biological strategies. This dynamic validation process helps maintain the integrity of the bio-inspired solutions (Shin et al., 2013).

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By leveraging AR technologies, the biomimicry design process becomes more robust and effective, aligning with modern, technology-driven approaches to innovation and sustainability.

Biology as a model and inventions:

Nature has an enormous pool of inventions that passed the harsh test of practicality and durability in a changing environment. To harness the most from nature's capabilities, it is critical to bridge between biology and engineering and see the cooperation of experts from both fields. This bridging effort can help turn nature's capabilities into engineering capabilities, tools and mechanisms. To approach nature in engineering terms, it is necessary to sort biological capabilities along technological categories. Namely, one can take biologically identified characteristics and seek an analogy in terms of engineering, as shown in the table.

Characteristic similarities of biology and engineering systems		
Biology	Engineering	Bioengineering, biomimetics, bionics and biomechanics
Body	System	System with multifunctional materials and structures are developed emulating the capability of biological systems
Skleton and bones	Structure and support struts	Support structures are part of every man-made system
Brain	Computr	Advances in computers are being made emulating the operation of the human brain
Intelligence	Artificial intelligence	There are numerous aspects of artificial intelligence that have been inspired by biology including augmented reality, autonomous systems, computational intelligence, expert systems, fuzzy logic, etc.
Senses	Sensors	Computer vision, artificial vision, radar, and other proximity detectors all have direct biological analogies. However, at their best, the capability of the man-made sensors is nowhere near as good as biosensors
Muscles	Actuators	Electroactive polymers are actuators with functional similarity to natural muscles
Electrochemical power generation	Rechargeable battries	The use of biological materials to produce power will offer mechanical systems enormous advantages.

Table 2. Characteristic similarities of biology and engineering systems

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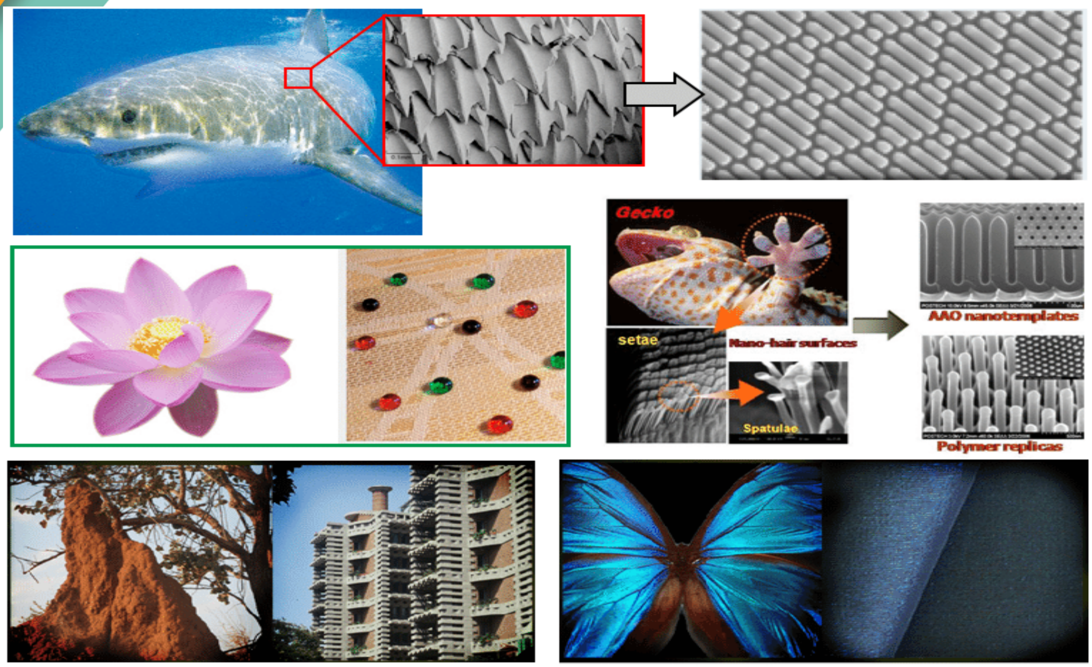
Nature capabilities:



Some of nature's capabilities can inspire new mechanisms, devices and robots. Examples may include the woodpecker's ability to impact wood while suppressing the effect from damaging its brain. Another inspiring capability is the ability of numerous creatures to operate with multiple mobility options including flying, digging, swimming, walking, hopping, running, climbing, crawling. Increasingly, biologically inspired capabilities are becoming practical including collision avoidance using whiskers or sonar, controlled camouflage, and materials with self-healing. One of the challenging capabilities will be to create miniature devices that can:

- fly with enormous maneuverability like a dragonfly;
- adhere to smooth and rough walls like a gecko;
- adapt to the texture, patterns and shape of the surrounding environment like a chameleon, or reconfigure their body to travel through very narrow tubes like an octopus;
- process complex three-dimensional (3D) images in real time;
- recycle mobility power for highly efficient operation and locomotion;
- self-replicate, self-grow using resources from the surrounding;
- chemically generate and store energy; and many other capabilities for which biology offers a model for science and engineering inspiration.

While many aspects of biology are still beyond our understanding, significant progress has been made.

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Enhance Module (Project Examples Using AR Tools for Biomimicry Education)

Augmented Reality (AR) tools bring new dimensions to biomimicry education by offering students an immersive, interactive way to engage with biological principles and translate them into innovative design solutions. Below are examples of how AR tools can adapt and enhance previously used projects.

Designed Inspired by Nature:(The Biomimicry Institute,2009)

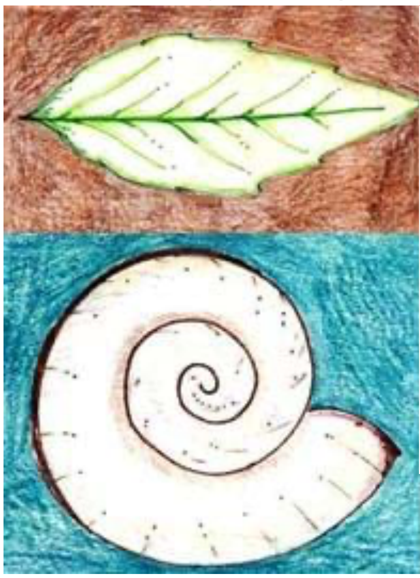

Figure 4. Biomimicry uses natural items as design inspiration.

In this sample activity at the basic level, students discover how engineers can use biomimicry to enhance their designs. They learn how the careful observation of nature—becoming a nature detective, so to speak, can lead to innovations and products. In this activity, students reverse engineer a flower to glean design ideas for new products.

- Engineering connection: Plants and animals are indeed nature's engineers. For example, a leaf can harness solar energy more efficiently than our best solar panels. Over millions of years, plants and animals have developed ingenious ways to survive on Earth. As engineers, we can consult nature to improve upon our existing designs and products. By studying nature, we can also gain inspiration for designs that never existed.

After this activity, students should be able to:

- Explain how biomimicry can be used to enhance engineering design.
- Describe the process of reverse engineering an object.
- Explain how brainstorming in a team can lead to more creative ideas.

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Before Activity

1. Gather materials.
2. Make copies of the Exploring Biomimicry Worksheet.
3. Review the above examples of biomimicry (more examples can be found through resources listed in the Reference section).
4. Practice reverse engineering a flower to prepare for the types of questions the students will ask.

With the Students

Part I: Reverse Engineering

1. Review the main concepts of biomimicry and present several case studies to motivate students.
2. (recommended) Complete the pre-assessment activity before conducting the main activity. This helps set the stage for the reverse engineering challenge.
3. Divide the class into groups of 2-3 students each.
4. Give each group a worksheet.
5. Use the worksheet to review the concept and procedure of reverse engineering before handing teams their flowers and tools. You could even require each team to answer an Investigating Question before handing out the materials.
6. Give each group a set of reverse engineering tools, such as toothpicks, tweezers, cutting tools, magnifying glasses and plastic bags.
7. Direct students to begin reverse engineering their flowers. Make sure the groups are following their worksheets, which outline the following four steps:
   a. Carefully take apart the flower and sketch its different components.
   b. Describe the colors and textures of the flower. Why was the flower created with these materials?
   c. Describe the overall shape and structure of the flower. What challenge might the flower solve by having this shape and structure?
   d. How could an engineer mimic the material, color, shape and structure of the flower to design something new?
   e. What scientific concepts that you have learned about before relate to the flower? How could you use these in your design?

Original Activity: Students reverse-engineer a flower to understand its structure, materials, and functional design. Enhanced with AR:

- Use tools like **JigSpace** to provide 3D AR models of flowers, enabling students to virtually explore their internal structures and understand their form-to-function relationships.
- Simulate how petals interact with environmental elements, such as shielding pollen from wind or refracting light to attract pollinators.
- Enable disassembly of virtual models, allowing students to observe key structural components like petal texture or stem flexibility, fostering deeper ecological understanding.

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New Learning Outcome: Students gain insight into applying biological structures to real-world engineering challenges, such as creating water-repellent surfaces or sustainable materials.

Part II: Product Design

1. Once students are finished reverse engineering the flowers, ask them to brainstorm potential new products based on what they observed. For example, products inspired by the flower might be new waterproof clothing, a water catchment system for a house, lightweight building materials, a skyscraper that can sway in the wind without breaking, etc.
2. Have each group brainstorm potential products for about 10 minutes. Have them write down or draw everyone's ideas generated during the brainstorming process.
3. Ask groups to choose one final product to present to the class. Give students a list of design criteria or constraints. For instance: size, budget, materials, resources, cultural setting etc. This helps students to put on their "engineering hats." Examples might include one of the following:

- Require students to develop designs that help solve environmental problems.
- Require students to develop designs that help solve health/medical problems.
- Require students to develop designs that could be built in a developing country or rural area with limited resources.
- Give students a hypothetical budget, such as $100.
- Require that students' designs result in zero waste, that is use entirely reusable materials.

4. Give each group another 10 minutes to develop the best ideas for their final products. Require them to make sketches and notes about their products on a fresh sheet of paper. Have students incorporate the teacher's design constraints, as appropriate.
5. Evaluate the different designs to determine how well they meet the criteria/constraints.
6. Ask each group to present its product to the rest of the class. If groups feel comfortable, have them draw their ideas on the classroom board and answer other teams' questions about their products.
7. After all groups have presented, lead the post-asessment activity with the students.

Figure 5. Two students reverse engineer a sunflower, © 2009 by Regents of the University of Colorado

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Enhanced with AR:

- Leverage AR platforms such as **Assemblr EDU** to allow students to create virtual prototypes of bio-inspired designs.
- Simulate product functionality in real-time, such as waterproof clothing mimicking lotus leaves or lightweight materials modeled after plant structures.
- Collaborative AR environments encourage group brainstorming and enhance team-based problem-solving.

New Learning Outcome: Students learn to bridge biology and engineering by designing bio-inspired solutions with AR-enhanced feedback mechanisms.

Technologies and Mechanisms in the nature:

Automatically controlling the operation of system is limited if a simple software with only predetermined options is used. Increasingly, systems are being made brilliant using artificial intelligence, where the control algorithms mimic nature. Making these systems bright involves using artificial intelligence algorithms that provide critical control capabilities such as knowledge capture, representation and rezoning under uncertainly, planning, vision, face and feature tracking, language processing, mapping and navigation, natural language processing, and machine learning. Generally, artificial intelligence is a branch of computer science that studies the computational requirements for such tasks as perception, rezoning, and learning to allow the development of systems that perform these capabilities. Improving the understanding of human cognition is increasingly enabling scientists to understand the requirements for intelligence in general and allowing the development of intelligent devices, autonomous agents, and systems that cooperate with humans to enhance their abilities.

Numerous examples of mechanisms were inspired by observing biology; several examples are given herein.

- **Inchworm linear motors**
  The biological inchworm is a caterpillar of a group of moths called Geometridae, which has six front legs and four rear legs. Emulating the mobility mechanism of this larva, or caterpillar, led to the development of motors and linear actuators known as inchworms. These commercially available motors are driven by piezoelectric actuators (made by companies such as Burleigh Instruments). They can move at a speed of about 2 mm s^{-1} with a resolution of nanometers while providing hundreds of millimeters of traveling. The forces produced by these motors can reach over 30 N with zero backlash and high stability. Their non-magnetic content offers advantages for applications in test instruments such as magnetic resonance imagers (MRI). Compared to biological muscles, the piezoelectric actuated inchworms have zero-power dissipation when holding position.

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Inchworm mechanisms have many configurations where the unifying drive principle uses two brakes and an extender. These motors perform cyclic steps where the rear brake clamps onto a shaft, and an extender pushes the front brake forward. Then, the front brake clamps the shaft, releasing the rear brake and retracting the extender to move one step forward
and this step can be as small as 1 nm.

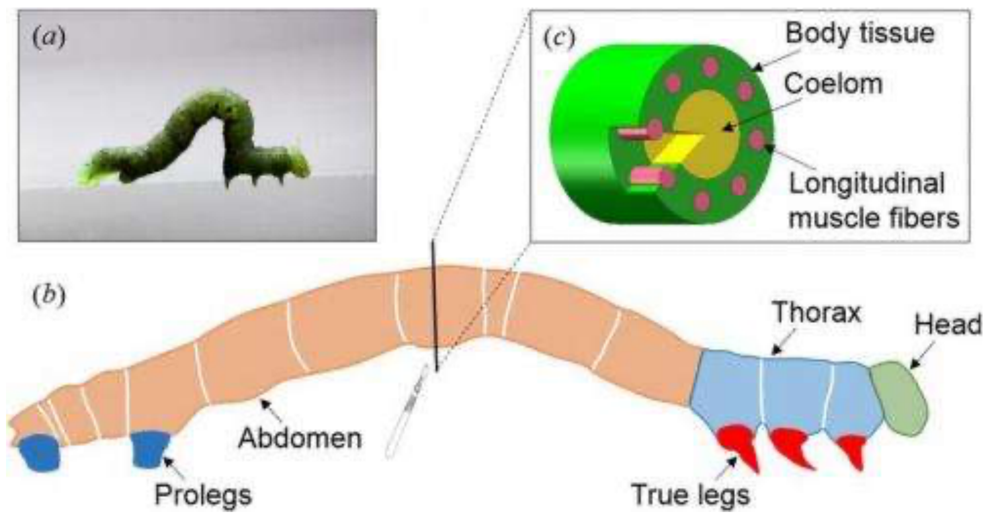

Figure 6. (a) A real inchworm, (b) side view sketch of an inchworm and (c) sketch of its main muscular structures. Credit: Wang, et al. ©2014 IOP Publishing

In fact, as a project for students, they explore how the inchworm's movement inspired piezoelectric motors, understanding its principles of mobility, efficiency, and practical applications in devices like MRI systems.

Enhanced Focus with AR

Using AR, students can:

1. Visualize the biomechanics of the inchworm's movement in 3D.
2. Simulate how piezoelectric actuators replicate this movement in linear motors.
3. Prototype bio-inspired motor designs virtually, testing their functionality and efficiency.

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1. Visualizing the Inchworm's Motion

- Tool: Use **JigSpace** or **Merge Cube** to provide a 3D interactive model of the inchworm's body and muscular structure.
- Activity:

  Students manipulate the AR model to observe how the inchworm's muscles coordinate cyclic movements.

  Simulations can show how the inchworm adapts its movement to different surfaces, emphasizing the functional principles behind its mobility.

2. Simulating the Piezoelectric Motor Mechanism

- Tool: Use **Assemblr EDU** or similar platforms to create a 3D AR simulation of piezoelectric actuators replicating the inchworm's movement.
- Activity:

  Students explore an AR model of the motor to understand the role of brakes, extenders, and piezoelectric actuators.

  Simulations allow students to adjust variables (e.g., motor speed, force, or resolution) and observe their effects in real time.

3. Prototyping Bio-Inspired Motors

- Tool: Leverage Reality Composer or **Sketchfab** for AR-based prototyping.
- Activity:

  Students design their own inchworm-inspired motors using AR tools.

  They can test the motors virtually, observing how adjustments to the motor's configuration impact its performance (e.g., precision, stability, or energy efficiency).

4. Real-World Applications with AR

- Tool: Use AR to simulate real-world applications of inchworm motors in medical, industrial, or robotic contexts.
- Activity:

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Students can see how the motor operates in devices like MRI scanners or robotic arms.

Simulations can highlight the advantages of inchworm-inspired designs, such as high precision and low energy dissipation.

New Learning Outcomes

1. Biomechanical Understanding: Students gain a deeper understanding of the inchworm's movement and how it inspired innovative engineering solutions.
2. Systems Thinking: AR fosters an integrated view of biological principles and engineering applications.
3. Design and Experimentation: Students develop and test bio-inspired designs in a virtual, risk-free environment, encouraging creativity and iterative learning.
4. Real-World Relevance: AR demonstrates the impact of biomimicry in practical contexts, making the learning experience more meaningful.

- **Pumping mechanisms**
  Pumping mechanisms in nature offer a great model for fluid and gas pumping devices. Nature uses various pumping mechanisms that are also used in mechanical pumps. The lungs pump air in and out (tidal pumping) via the use of the diaphragm that enables our breathing with the support of the inter-rib muscles. Peristaltic pumping is one of the most common forms of pumping in biological systems, where liquids are squeezed in the required direction. Such pumping is common in the digestive system. Pumping via valves and chambers that change volume is found in human and animal hearts, with expansion and contraction of chambers. The use of one-way valves is the key to the blood flow inside the veins, where the pressure is lower.

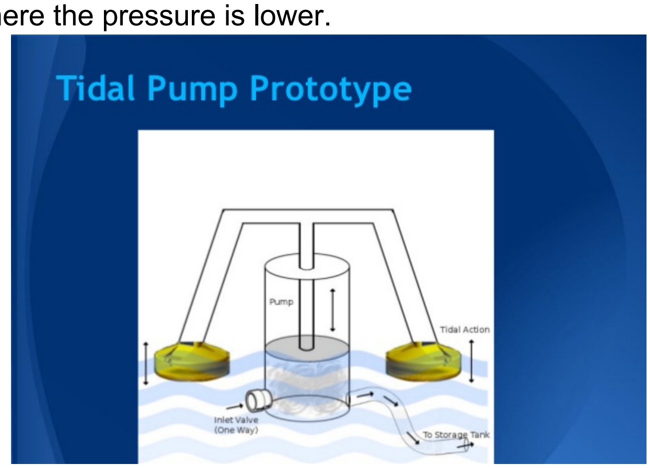

Figure 7. Tidal pump, https://www.slideshare.net

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By concidering this mechanism as a student's project, Students explore natural pumping mechanisms like the human heart or peristalsis in the digestive system.

Enhanced with AR:

- Use AR tools like **Merge Cube** to create interactive 3D models of biological pumps, enabling students to explore their anatomy and functionality.
- Simulations can demonstrate fluid dynamics, illustrating how one-way valves and pressure differences enable efficient fluid transport.
- Students can design virtual prototypes of bio-inspired pumps for applications like medical devices or irrigation systems.

New Learning Outcome: Students acquire a deeper understanding of fluid mechanics and its translation into efficient technological solutions.

- **Controlled adhesion**

  Controlled wet or dry adhesion is achieved by many organisms. Using a highly fibrillated microstructure, the Hemisphaerota cyanea (a beetle) uses wet adhesion that is based on capillary interaction. On the other hand, the gecko exhibits remarkable dry adhesion using van der Waals forces. Even though these forces provide low intrinsic energy (~50 m J m^{-2}), their effective localized application allow for the remarkable capability (Autumn et al 2002). Using this adhesion mechanism, the gecko can run on polished glass at a speed of about 1 m s−1 and attach its body to the wall using a single toe to support its body weight. This capability motivated efforts to mimic the gecko's adhesion mechanism and some limited success was reported. Such research was conducted by Autumn and Peattie (2003) who developed an artificial foot-hair tip model for a dry, self-cleaning adhesive that works under water and in vacuum.

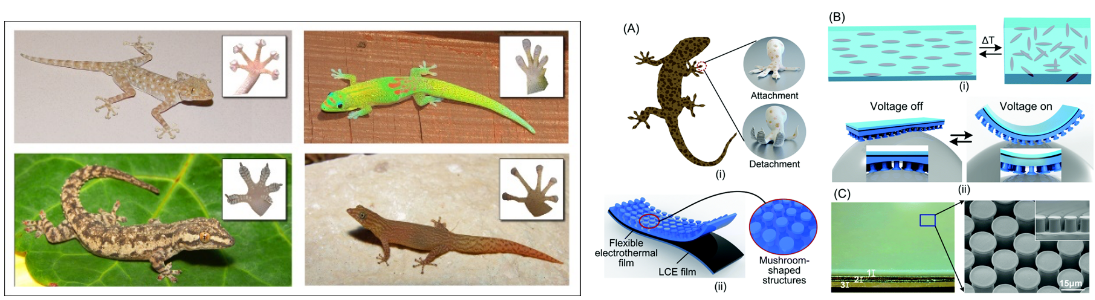

Figure 8. Gecko's adhesion specification, (Hongmiao Tian&all,2020)

As a project for students, this example can be examined by students to know how geckos adhere to surfaces and brainstorm ways to mimic this function.

Enhanced with AR:

- Utilize **Reality Composer** or similar tools to let students visualize gecko foot structures at a microscopic scale in AR.
- Interactive simulations can show how van der Waals forces enable adhesion, even on smooth surfaces.
- Students can test and adjust virtual designs inspired by gecko adhesion, such as robotics or medical devices.

New Learning Outcome: Students understand the science behind adhesion and its potential for innovative problem-solving, such as creating safer climbing equipment or underwater adhesives.

- **Honeycomb**

  The honeycomb is made by bees in total darkness and it consists of a perfect hexagonal cellular structure that offers an optimal packing shape. For honeybees, the geometry meets their need for making a structure that provides the maximum amount of stable containment (honey, larvae) using the minimum amount of material. For the same reasons, the honeycomb is an ideal structure for the construction of control surfaces of an aircraft and it can be found in the wing, elevators, tail, the floor, and many other parts that need strength and large dimensions while maintaining low weight.

Figure 10.3D Printed 'Homed' by Framlab Offers Shelter for New York's Homeless according to honeycomb.https://www.dezeen.com

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By interpreting this idea as a students' project, students study honeycomb geometry to understand its strength and material efficiency.

Enhanced with AR:

- Use AR tools like **Sketchfab** to provide immersive experiences of honeycomb structures, allowing students to analyze how their geometry optimizes space and material use.
- To demonstrate the direct utility of these principles, simulate real-world applications, such as honeycomb-inspired architectural designs or airplane components, in AR.

New Learning Outcome: Students connect the structural efficiency of natural designs to sustainable engineering and architectural practices.

Consideration of biomimetics for planetary application:

For future space exploration applications, biomimetics offers a pool of concepts that can potentially be used to enable new technologies and enhance the available capabilities. To take advantage of the potential benefits to future NASA missions that can be harvested from mimicking from nature. As a potential application of these materials, one can envision that availability of strong and robust artificial muscles based on EAP[1] materials may enable us in coming years to produce biomimetic legged robots that can run as fast as a cheetah, carry mass like a horse, climb steep cliffs like a gecko, reconfigure their body like an octopus, fly like a bird and dig tunnels like a gopher. This is an incredible vision for robots that can potentially be used to explore planets in the universe, and it may lead to future

planetary mission plans that are based on a script for the robot's operation following science fiction ideas. Some of the tasks that such robots may need to perform include autonomously operate to detect water, various resources, and possibly biological indicators in the search for past or present life or even construct facilities for future human habitats. Once such robots are made sufficiently reliable to operate in the harsh environment of space, they will be able to act as human surrogates in executing tasks that require human's capabilities without subjecting real persons to any unnecessary hazards.

Space applications are among the most demanding in terms of the harshness of the operating conditions, requiring a high level of robustness and durability. Making biomimetic capability using electroactive material will potentially allow NASA to conduct missions on other planets using robots that emulate human operation ahead of the landing of humans. Generally, the requirements and challenges associated with making hardware based on the emerging technology for space flight are very difficult to overcome.

However, since such applications usually involve producing only small batches, they can provide an important avenue for introducing and experimenting with new actuators and devices. This is in contrast to commercial applications, for which issues of mass production, consumer demand and cost per unit can be critical to the transfer of technology to practical use. Generally, making biologically inspired robots that are driven by EAP actuators may have capabilities that are superior to natural creatures since these robots are not constrained by evolution and survival

[1] Electroactive polymers, or EAPs, are polymers that exhibit a change in size or shape when stimulated by an electric field. The most common applications of this type of material are in actuators and sensors.

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needs that are critical to biological creatures. Bar-Cohen and his co-investigators constructed a miniature robotic arm that was lifted by an EAP actuator that is based on rolled dielectric elastomer and operated as a linear actuator. Telepresence combined with virtual reality using haptic interfacing offers another important potential for space applications particularly for avoiding the direct contact of humans with hazardous conditions.

A novel design was conceived by Bar-Cohen and his research team, where a minimally invasive robotic arm as a surgical tool can be constructed in an octopus configuration with multiple degrees of freedom tentacles equipped with various tools. To implement such a possibility, a combination of EAP as actuators and electrorheological fluids (ERFs) was considered where the rigidity of such a flexible robotic arm can be controlled, and it can be operated as a haptic interface.

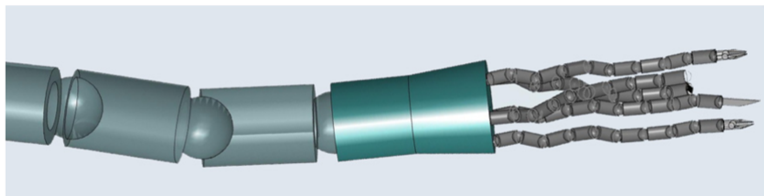

Figure 17.A graphic view of an octopus-configured catheter for surgical applications. (Bar-Cohen,2006)

The **Consideration of Biomimetics for Planetary Application** project, which envisions biomimetic robots for space exploration, can also be significantly enhanced with AR tools. By integrating AR, students and researchers can simulate, visualize, and experiment with bio-inspired robotic concepts, improving their understanding and creativity in designing solutions for harsh planetary environments.
The project explores biomimetic concepts, such as artificial muscles, gecko-like climbing, and octopus-like reconfiguration, to create robots that can operate in harsh planetary conditions.

Enhanced Focus with AR:

Using AR, students can:

1. Visualize the movement and adaptability of biomimetic designs in extreme environments.
2. Simulate tasks such as resource detection or habitat construction on other planets.
3. Prototype and test bio-inspired robots in virtual simulations of planetary conditions.

1. Exploring Biomimetic Movement

- Tool: Use JigSpace or Assemblr EDU to provide 3D AR models of biomimetic robots inspired by cheetahs, geckos, or octopuses.
- Activity:

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Students manipulate AR models to observe how biological adaptations (e.g., gecko adhesion or cheetah speed) are translated into robotic functions.

Simulate movements like climbing cliffs or reconfiguring shapes for different tasks.

2. Simulating Space Applications

- Tool: Leverage Merge Cube to create AR environments replicating planetary surfaces, such as Mars or the Moon.
- Activity:

Students test AR-based robots on virtual terrains with simulated environmental challenges, such as low gravity or extreme temperatures.

Visualize how artificial muscles and biomimetic designs enable tasks like resource extraction or habitat assembly.

3. Prototyping Robots with AR

- Tool: Use Reality Composer to let students design and modify bio-inspired robotic components.
- Activity:

Students prototype robotic arms with EAP actuators or gecko-inspired climbing mechanisms.

Simulate how these designs handle specific tasks, such as collecting samples or constructing modular habitats.

4. Collaborative Design Challenges

- Tool: Utilize **CoSpaces Edu** for group-based AR simulations.
- Activity:

Teams design multifunctional robots that combine multiple biomimetic principles (e.g., a gecko-inspired climbing arm and a cheetah-inspired running mechanism).

Use AR to visualize and refine these designs collaboratively, presenting their robots' capabilities in a simulated planetary mission.

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Conclusion

Integrating biomimicry into educational practices offers students a unique opportunity to explore the intersection of biology, engineering, and design, fostering creativity and innovation. Incorporating Augmented Reality (AR) tools makes learning more immersive, interactive, and engaging. These tools enable students to visualize complex biological systems, simulate real-world applications, and prototype bio-inspired solutions in dynamic virtual environments.

This training unit has been structured to guide learners through the phases of Explore, Execute, and Enhance phases, ensuring a comprehensive approach to understanding and applying biomimicry principles. In the Explore phase, students build foundational knowledge of bio-inspired concepts and utilize AR to visualize biological models. The Execute phase emphasizes hands-on projects, collaborative problem-solving, and real-time feedback through AR simulations. Finally, the Enhance phase introduces advanced learning strategies, such as gamification and AR-based assessments, to deepen understanding and encourage innovation.

The following table summarizes the core elements of each phase, detailing how AR tools are integrated to support the learning objectives. By embedding this table in the training unit, educators and learners can easily reference the framework and appreciate the transformative role of AR in biomimicry education.

Phase	Description
Explore	- **Research and Discovery**: Students engage with foundational concepts of biomimicry, exploring biological principles like form-to-function fit and optimization through natural processes.
	- **Content Development**: Interactive AR tools like JigSpace provide 3D models (e.g., lotus leaf microstructure, honeycomb geometry) to visualize concepts and relate them to technical applications.
	- **Needs Analysis**: Teachers and students analyze the challenges in abstracting biological strategies for engineering applications.
Execute	- **Curriculum Implementation**: Lessons include projects such as reverse engineering flowers or designing bio-inspired robots.
	- **Interactive Exercises**: AR-based tools like Assemblr EDU are used for prototyping and simulations. For example, students design virtual gecko-inspired climbing tools or simulate inchworm-inspired linear actuators.
	- **Feedback Collection:** Teachers gather insights from AR-enhanced projects, focusing on how AR improves understanding and engagement.
Enhance	- **AR Integration**: Introduce AR-enhanced visualizations for advanced biomimicry concepts, such as robotic simulations inspired by geckos or cheetahs.
	- **Interactive Learning:** Students explore planetary applications, testing AR-based models for robots in extreme environments like Mars. Collaborative tools like CoSpaces Edu facilitate teamwork in designing multi-functional robots.
	Gamified Content: Points, badges, and leaderboards are integrated into AR simulations (e.g., collecting rewards for solving biomimicry design challenges).
	AR-Based Assessments: AR-enabled assessments allow students to demonstrate biomimicry applications interactively, such as simulating environmental adaptations or testing bio-inspired prototypes.

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References:

Autumn K and Peattie A M 2003 Mechanisms of adhesion in geckos J. Integr. Comp. Biol. 42 1081–90.

Autumn K, Sitti M, Liang Y A, Peattie A M, Hanen W R, Sponberg S, Kenny T W, Fearing R, Israelachvili J N and Full R J 2002 Evidence for van der Waals attachment by gecko foot-hairs inspires design of synthetic adhesive Proc. Natl Acad. Sci. USA 99 12252–6.

Benyus, Janine M. Biomimicry: Innovation Inspired by Nature. New York, NY: William Morrow and Company, Inc., 1997.

Ciloglu.T, Ustun.A.B. 2023. The Effects of Mobile AR-based Biology Learning Experience on Students' Motivation, Self-Efficacy, and Attitudes in Online Learning. https://doi.org/10.1007/s10956-023-10030-7

Dzenis Y 2004 Spinning continuous fibers for nanotechnology Science 304 1917–9.

Hwang J, Jeong Y, Park JM, Lee KH, Hong JW, Choi J.2015. Biomimetics: forecasting the future of science, engineering, and medicine. DOI: https://doi.org/10.2147/IJN.S83642.

Helena Hashemi Farzaneh.2019. A Practical Guide to Bio-inspired Design, https://doi.org/10.1007/978-3-662-57684-7, ISBN 978-3-662-57683-0.

Hongmiao Tian, Haoran Liu , Jinyou Shao ORCID logo, Shuai Li , Xiangming Li and Xiaoming Chen.2020. An electrically active gecko-effect soft gripper under a low voltage by mimicking gecko's adhesive structures and toe muscles. DOI: 10.1039/D0SM00787K.

Keto JE (1960) Bionics - new frontiers of technology through fusion of the bio and physio disciplines (keynote address). In: Robinette JC (ed) Bionics Symposium: Living prototypes - the key to new technology, pp 7–12.

Lukosch.S, Billinghurst.M, Alem.L, Kiyokawa.K. 2015.Collaboration in Augmented Reality. DOI 10.1007/s10606-015-9239-0

Mansour.N, Aras.C, Staarman.J.K,Bader.S, Alotaibi.M. 2024. Embodied learning of science concepts through augmented reality technology. https://doi.org/10.1007/s10639-024-13120-0

Nachtigall W, Wisser A (2015) Bionics by examples: 250 scenarios from classical to modern times. Springer, Cham, Heidelberg, New York, Dordrecht, London.

Nilsson, S., Johansson, B., Jönsson, A., (2008), Design of Augmented Reality for Collaboration, Proceedings of The 7th ACM SIGGRAPH International Conference on Virtual-Reality Continuum and Its Applications in Industry, VRCAI 2008. https://doi.org/10.1145/1477862.1477920

Shin.T.J, Jennings.C, Ed.D. 2013. AUGMENTED REALITY AND DESIGN PROCESS: THE NEW ROLE OF AUGMENTED REALITY IN DESIGN PROCESS. IDSA 2013 EDUCATION SYMPOSIUM, https://www.idsa.org/wp-content/uploads/Shin_Ted-Paper_AUGMENTED_REALITY_AND_DESIGN_PROCESS.pdf?utm_source=chatgpt.com

Project Number: KA220-BW-23-30-126516

Subran.S, Diyana Mahmud.S.N. 2024. Augmented Reality (AR) Technology in Biology and Life Science Education: A Systematic Literature Review (SLR). DOI:10.6007/IJARPED/v13-i1/20455

The Biomimicry Institute, "Inspiring, educating and connecting biomimics through the world," 2007-2009. Accessed August 5, 2009. http://www.biomimicryinstitute.org,Copyright © 2009 by Regents of the University of Colorado.

Yoseph Bar-Cohen.2012. Biomimetics: Nature-Based Innovation,Taylor & Francis Group.

Yoseph Bar-Cohen.2006. Biomimetics—using nature to inspire human innovation. CA 91109-8099, USA.

Vardar-Ulu.D, Ragab.S.E, Agrawal.S, Dutta.S .2024. Using augmented reality in molecular case studies to enhance biomolecular structure-function explorations in undergraduate classrooms. https://doi.org/10.1128/jmbe.00019-24

Wei Wang, et al. "Locomotion of inchworm-inspired robot made of smart soft composite (SSC)." Bioinspiration & Biomimetics. DOI: 10.1088/1748-3182/9/4/046006.

Project Number: KA220-BW-23-30-126516

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BIO-INSPIRED STEM TOPICS FOR ENGAGING YOUNG GENERATIONS
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