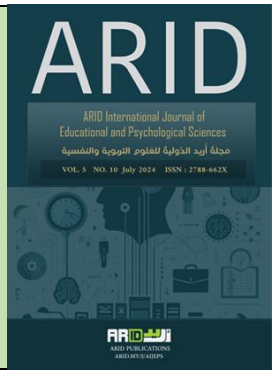
ARID Journals

ARID International Journal of Educational and Psychological Sciences (AIJEPS)

Journal home page: http://arid.my/j/aijeps



مَجلةُ أُريد الدَّوليةُ للعُلومِ التربوية والنفسية

العدد 10، المجلد 5، كانون الثاني 2024 م

Biomimicry in Science Classrooms: Learning Design Thinking Skills Inspired by Nature "A Proposed Teaching Model"

Prof. Marwa Mohamed Elbaz

Professor of Curriculum and Methods of Teaching Science, Faculty of Education, Port Said University, Egypt

m_elbaz2009@edu.psu.edu.eg
arid.my/0001-3988
https://doi.org/10.36772/arid.aijeps.2024.5105

ARTICLE INFO

Article history:
Received 18/01/2024
Received in revised form 11/03/2024
Accepted 27/05/2024
Available online 15/07/2024
https://doi.org/10.36772/arid.aijeps.2024.5105

ABSTRACT

Biomimicry is one of the modern approaches that draw inspiration from natural models and processes for solutions to address human challenges, and it is also a new educational trend that has emerged to meet the needs of education, especially education for sustainability. The study aims to enrich the educational literature with qualitative additions about the applications of biomimicry in education, and to present a teaching model based on biomimicry to develop design skills among learners of science and interdisciplinary education. The study used a qualitative approach, specifically an integrative literature review methodology, to evaluate and analyze studies related to biomimicry and its impact on teaching and learning; With the aim of enhancing the theoretical and applied understanding of biomimicry in the context of education. The study provided a theoretical framework on: the concept of biomimetics, its levels and principles, how educational literature addressed the use of biomimicry in education and teaching, the relationship between biomimicry and design skills, and finally, it presented an effective framework for a teaching model using biomimicry that can be applied to develop design thinking skills. For learners across different educational stages.

Keywords:Biomimicry – Science Education- Interdisciplinary Education - Design Thinking - Education for Sustainability.

الملخص

تُعد المحاكاة الحيوية واحدًا من الأساليب الحديثة التي تستلهم من النماذج والعمليات الطبيعية حلولًا لمواجهة التحديات البشرية، وهو أيضًا اتجاه تربوي جديد ظهر لتلبية احتياجات التعليم، خاصة التعليم من أجل الإستدامة. تهدف الدراسة إلى إثراء الأدب التربوي بإضافات نوعية حول تطبيقات المحاكاة الحيوية في التعليم، وتقديم نموذج تدريسي قائم على المحاكاة الحيوية لتنمية مهارات التفكير التصميمي لدى متعلمي العلوم والتعليم متعدد التخصصات. استخدمت الدراسة المنهج النوعي تحديدًا منهجية المراجعة التكاملية للأدبيات، لتقييم وتحليل الدراسات المتعلقة بالمحاكاة الحيوية وتأثيرها على التعليم والتعلم؛ بهدف تعزيز الفهم النظري والتطبيقي للمحاكاة الحيوية في سياق التعليم. قدمت الدراسة إطارًا نظرياً حول كل من: مفهوم علم المحاكاة الحيوية ومستوياته ومبادئه، كيف تناول الأدب التربوي استخدام المحاكاة الحيوية في التعليم والتدريس، العلاقة بين المحاكاة الحيوية ومهارات التصميم، وأخيرًا، قدمت إطارًا فعّالًا لنموذج التدريسي باستخدام المحاكاة الحيوية يمكن تطبيقه لتنمية مهارات التفكير التصميمي لدى المتعلمين عبر المراحل التعليمية المختلفة.

الكلمات المفتاحية: المحاكاة الحيوية- تعليم العلوم- التعليم متعدد التخصصات- التفكير التصميمي- التعليم من أجل الإستدامة.

Introduction:

Many human problems and challenges have emerged with man's frequent consumption of natural resources and unwise interaction with them. This causes natural scientists to contemplate and search for ways in which nature and living organisms solve the problems they face and how to correct themselves, which is known as the science of "biomimicry". Biomimetics emerged as a response to the growing need for sustainable and innovative solutions inspired by nature. The origin of this science goes back to the concept of imitating biological processes and forms found in nature to solve human problems. Benyus, Janine, is considered the founder of biomimicry in 1997, as she introduced this concept to the world through her book "Biomimicry: Innovation Inspired by Nature." Bio: Innovation Inspired by Nature), in which I demonstrated how human innovation can leverage nature's strategies and solutions, which have evolved over millions of years to be effective and sustainable. It provided practical examples of how biomimicry can be applied in multiple fields such as architecture, agriculture, energy, and industrial design, stressing the importance of learning from natural systems to solve contemporary environmental and technological problems (Benyus, 2002, Biomimicry Institute, 2024).

In the context of education, educationalists argue that learners become more disconnected from nature and reluctant to interact directly with living things. The widespread urbanization of the world has also reduced the opportunities for learners to interact with nature, which limits their understanding of natural life. Some initiatives such as eco-schools have emerged to address these concerns, but they have not achieved widespread in society except for a select group of privileged learners. However, significant efforts are being made in this regard, with new approaches to implementation being explored. One of these approaches is biomimicry, which can provide opportunities to enhance creativity and critical thinking in learners, through practical educational experiences based on observation and learning from nature (Stevens, et al, 2021; Adıgüzel, et al, 2024).

The discovery of biomimicry as a concept has gained great recognition and attention around the world for its ability to address human challenges, and in general, the integration of biomimicry into education enhances learners' ability to understand the natural world more deeply, promotes sustainable practices, and prepares them to address complex challenges in different ways (MacKinnon, et al. 2020). Biomimicry is therefore one of the promising approaches that can meet the needs of science and interdisciplinary education by drawing inspiration from natural models and processes. Therefore, this study aims to present a teaching model based on biomimicry to develop design thinking skills through science education or interdisciplinary education and to explain how this model can enhance understanding of nature and sustainable design thinking skills among learners considering a changing educational environment. The study problem was defined in the following questions:

1. **What is biomimicry and what are its levels and principles?**
2. **How has the educational literature addressed the use of biomimicry in the context of teaching and learning?**
3. **What is the relationship between biomimicry and design skills?**
4. **What teaching model does the study suggest for using biomimicry to learning design thinking skills?**

Methodology

The research relies on a qualitative approach, specifically the Integrative Literature Review Approach proposed by (Snyder, 2019) to evaluate and analyze studies and literature related to biomimicry and its impact on teaching and learning, which is an excellent way to collect and integrate research results, provide convincing evidence, and discover Areas for future exploration. Below are the steps of this methodology in detail:

A. **Literature Collection**: A variety of scientific papers such as conference proceedings, journal articles, book chapters, and books were collected by searching studies indexed in

the Web of Science (WOS) database using the keywords “biomimicry,” “biomimicry in education.” Relevant studies were then selected by scanning the ERIC, Wiley, and Scopus databases as well as the National Dissertation Center and ProQuest databases and included in the review (all cited in the reference list). The review focused on studies dealing with biomimicry and its applications in education.

B. **Theoretical Framework**: The review was conducted to create and develop strong theoretical and conceptual frameworks about the use of biomimicry in interdisciplinary education. As for the research variables that were reviewed, they include biomimicry, design thinking, engineering design, science education, and interdisciplinary education.

C. **Qualitative Analysis:** A qualitative analysis of the collected research was conducted to evaluate ideas and concepts related to the topic. The analysis resulted in building a teaching model using biomimicry to develop design thinking skills in science curricula and interdisciplinary curricula.

D. **Evaluation:** The results of the analysis were evaluated to highlight the potential of biomimicry to support teaching design thinking skills.

E. **Results:** The review concluded that biomimicry holds great potential to support the learning of design thinking skills and scientific model design among students through science and interdisciplinary curricula.

Objectives

The study aimed to provide an integrative review of the educational literature related to biomimicry, design thinking skills, and the field of engineering design as one of the main areas in the Next Generation Standards (NGSS). This aims to build a teaching model using biomimicry to develop design thinking skills in science and interdisciplinary curricula.

Importance

1- Drawing the attention of those responsible for developing science curricula and interdisciplinary curricula to the necessity of using biomimicry in the curricula, allowing for linking different specializations and developing different skills among learners.

2- Benefiting science teachers by presenting a proposed teaching model based on biomimicry to develop design thinking skills for learners at different academic levels.

3- Benefiting researchers by presenting a new teaching model based on biomimicry that can be applied in other research, as the current study is limited to only the theoretical study of biomimicry by reviewing the educational literature.

Results

The current part of the study deals with answering the study questions through a review of literature closely related to the study problem. This is as follows:

Results of the First Question:

The first question ***states (What is the science of biomimicry and what are its levels and principles?)*** By referring to previous literature and studies, it was possible to answer the question as follows:

The Concept of Biomimicry Science

Biomimicry (meaning bios means life - mimesis (meaning to imitate) is a new science that studies the best natural ideas and then imitates these designs and processes to solve human problems (Benyus, 2002), that is, it is the practice of applying lessons learned from nature to invent technologies that are healthier and more sustainable for humans. Biomimicry designers focus on understanding and learning to imitate the strategies used by living organisms, intending to create design solutions that blend biology, nature, engineering, and technology (Biomimicry Institute, 2024).

Levels of Biomimicry

There are main levels of biomimicry explained by (Benyus, 2002; Bianciardi, et al, 2017; Fahmy, 2018; Abdul-Wahab, et al, 2022) as follows:

1. **Organism Level Biomimicry:**

It focuses on imitating the distinctive traits and characteristics of a particular organism. This can include the physical structures, physical properties, or biological processes that occur in a single organism. Example: An antibacterial surface design inspired by shark skin, where tiny scales help prevent the adhesion of bacteria.

2. **Behavioral Level Biomimicry:**

It involves the study of the behaviors of living organisms and their application in technology and human systems. This level focuses on how organisms interact with their environment and how they solve problems in innovative ways. Example: Developing robots that use ants' behavior strategies in search and rescue, which rely on cooperation between robots and the distribution of tasks.

3. **Ecosystem Level Biomimicry:**

It is concerned with mimicking complete ecosystems and the complex interactions between organisms and their environments. This level aims to develop sustainable systems based on the principles of environmental balance and integration between system components. Example: Designing sustainable cities based on natural forest principles, such as using renewable energy, recycling water, and diversifying urban environments to enhance biodiversity and improve quality of life. Another example: designing agricultural systems based on natural forest principles to enhance biodiversity and reduce the need for artificial inputs.

There is a sub-classification of more detailed levels of biomimetics, all of which are also included within each of the three main levels mentioned above and differ depending on the level (organism - organism behavior - ecosystem), which are:

A. Form Biomimicry:

It involves imitating the physical shapes and patterns found in nature - whether the shape of living organisms, the shape of organisms' housing, or the shape of environmental systems - to improve engineering and aesthetic design. This includes imitating external shapes such as shark skin, butterfly wings, or tree leaves. Example: Aircraft design is inspired by the shape of bird wings to improve aerodynamics and the use of the shape of whale fins in the design of wind turbine blades to improve their efficiency.

B. Function Biomimicry:

It focuses on imitating biological functions or processes to improve the performance of systems. How organisms perform certain tasks is studied and applied in technology and engineering. Example: development of waterproof materials inspired by the function of the lotus leaf in repelling water.

C. Structural Biomimicry:

It relates to the imitation of the internal structures of living organisms that give them strength, flexibility, or other properties. This can include microscopic or electronic structures. Example: The design of bridges and engineering structures is inspired by strong, lightweight bone structures.

D. Material Biomimicry:

It focuses on developing new materials through the study of biological materials. This includes imitating the chemical composition and physical properties of natural materials. Example: creating strong, flexible fibers inspired by spider silk.

E. Process Biomimicry:

It involves imitating the biological and chemical processes that occur in living organisms to improve industrial and technological processes such as how they generate energy, clean water, or produce materials. Example: using the principles of photosynthesis to develop more efficient solar cells.

Principles of Biomimicry

The Nature Principles of Biomimicry, also known as the Life Principles, are a set of nature-inspired guidelines that help guide the design of sustainable products and systems. These principles were developed by the Biomimicry 3.8 Institute (Biomimicry 3.8, 2013) to promote sustainable design thinking and are:

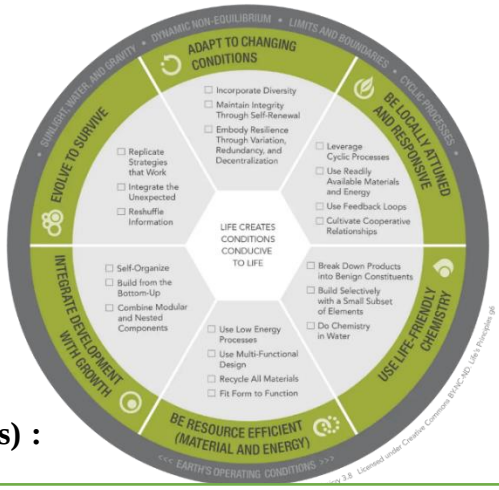


Figure (1): Principles of biomimicry (Biomimicry3.8, 2013)

1- **Evolve to Survive**: It means constantly adapting and evolving living organisms to suit their environments and achieve survival. Therefore, designs must be flexible and adaptable to environmental changes.

2- **Efficient use of Resources (Adapt to Changing Conditions) :** means that living organisms quickly adapt to changing environmental conditions. Therefore, designs should be able to adapt to constant changes.

3- **Celebrating Diversity:** This means that living organisms enhance biological diversity to achieve stability and resilience. Therefore, designs should integrate multiple and diverse elements to achieve effectiveness.

4- **Using Life-Friendly Chemistry:** means that living organisms use safe environmental chemistry to achieve functional goals. Therefore, designs must use materials that are environmentally harmless and safe for humans.

5- **Recycle Everything (Be Resource Efficient):** This means that living organisms reuse materials and energy efficiently to achieve effectiveness. Therefore, designs should be resource-efficient and promote recycling.

6- **Interaction with other Systems (Integrate Development with Growth):** This means that living organisms cooperate and integrate to achieve environmental balance. Therefore, designs must be harmoniously integrated with the natural environment.

7- **Achieving Sustainability (Optimize Rather than Maximize):** This means that living organisms seek to improve processes rather than maximize resource consumption. Therefore, designs should focus on continuous improvement to achieve efficiency and sustainability.

Through the previously presented explanation of the concept of biomimetics, its levels, and principles, biomimicry aims to inspire and imitate biological models, systems, and processes existing in nature to solve human problems innovatively and sustainably. This science is characterized by the integration of biological knowledge with engineering and design to develop products, technologies, and systems that mimic those found in the natural world. This science can also be utilized in teaching science and interdisciplinary curricula and used as a teaching input to design solutions to scientific problems that learners try to explore and solve in science classrooms, and this is what the next part of the study presents.

Results of the Second Question:

The second question states **(How has the educational literature addressed the use of biomimicry in the context of teaching and learning?)** By referring to previous literature and studies, the question can be answered as follows:

Teaching biomimicry in the classroom

Biomimicry as a contextual learning method is a powerful tool that can be used in education to integrate skills training across the sciences. Biomimicry-inspired projects encourage students to acquire different knowledge and skills while learning to think sustainably. This method can be applied to many pure sciences that can help in applying twenty-first-century skills in interdisciplinary educational curricula (Roobeek, 2019)

Educational studies have recently focused on using biomimicry in education, as one of the modern trends in interdisciplinary education and education for sustainability. These studies have confirmed the importance of biomimicry in developing multiple aspects of students at different educational levels, and these studies include:

The study by ***William, et al (2018)***, presented a set of successful activities that were used to teach biomimicry to first-year primary school students, and the study by ***Roobeek (2019),*** aimed to determine the role that biomimicry can play in bridging the gaps identified by teachers between the current and desired educational situation. In the Netherlands. These gaps were identified by conducting a needs analysis and using the results to define standards for new educational materials about biomimicry. The developed materials were evaluated and analyzed, which together with the needs analysis formed the basis of a consultation report for the Dutch Biomimicry Foundation - ***BiomimicryNL***, which seeks to include biomimicry in secondary education. The study found that biomimicry has the potential to be an effective part of secondary education and demonstrated that educational materials related to biomimicry add value through close alignment with modern teaching methods. The biomimetic-based approach ensures a student-centered learning experience, which arouses students' curiosity and allows for active learning. In addition, biomimetic-based educational materials integrate interactive projects that comprehensively cover the most in-demand skills of the 21st century.

Canbazoğlu, et al (2021) study also concluded that biomimetic-based activities help students explore scientific concepts such as air pollution and structural properties of various organisms. The study observed that after the biomimicry activities, students developed diverse ideas regarding environmental tools inspired by nature. Moreover, it was found that examining the structural systems and properties of organisms in the nature-inspired process facilitated learners to acquire scientific knowledge more effectively.

Oguntona & Aigbavboa's (2023b) study provides a conceptual framework for applying biomimetic principles to higher education teaching and learning and provides examples of nature-inspired teaching methods, such as experiential learning, collaborative learning, and real-world problem-solving. It also highlighted the challenges and potential benefits of using biomimetic principles in higher education. She asserts that using biomimetic principles can transform teaching and learning practices in higher education and help prepare students to meet the complex challenges of the 21st century.

Deliman & Lott's (2023) study analyzed the content of several picture books that focused on the topic of ecology, three recently published picture books that will serve as anchors for creating inquiry-based activities for first graders, and described opportunities to enhance understanding through the use of High-quality picture books can be read aloud in early childhood classrooms and provide examples of how the Next Generation Science Standards can connect NGSS to literacy standards while implementing inquiry-based learning engagements.

Adıgüzel, et al (2024) referred to the biomimetic approach as educational practices that rely on multidisciplinary scientific activities and are often associated with the STEM approach. The impact of the biomimetic approach on the learning and teaching process was evaluated, based on the results of studies related to teaching practices using the biomimetic approach. The research was conducted using a systematic review method. For 16 scientific studies. To examine the impact of the biomimetic approach to education on students' skills across multiple domains, including cognitive, metacognitive, affective, and social domains, the results showed that incorporating biomimetics into educational activities improves students' scientific and cognitive skills, enhances critical and creative thinking, and increases awareness of the relationship between Technology and nature. It also encourages students to use a variety of educational resources, which enhances scientific research and problem-solving skills. In addition, biomimicry stimulates motivation to learn and develop leadership skills and responsible environmental behavior. These results are evidence of the great potential of biomimicry in improving the educational experience and enhancing 21st century skills in students, making it a promising approach to achieving comprehensive and sustainable education.

(Adıgüzel, et al, 2024) adds a description of educational activities based on biomimicry as those activities that depend on drawing inspiration from nature and applying them in the educational process to enhance students' understanding and improve their skills in multiple disciplines. These activities are implemented by integrating the principles of biomimicry into curriculum, which enhances the interaction between students, the natural environment and technology.

Based on the previous presentation, there is a clear and specific understanding of the concept of biomimicry as a stand-alone science, but the literature and educational studies differed about the concept of biomimicry in the educational context. Is it an educational approach, multidisciplinary educational activities, teaching practices, or scientific content that can be integrated into educational curricula? Biomimicry is considered an educational approach if it is used as a theoretical and methodological framework for designing curricula and educational programs, where teachers and students can follow methods and strategies inspired by nature to solve problems and promote active learning. When biomimicry is used as interdisciplinary educational activities, it allows the integration of knowledge and skills from different scientific fields, which helps students develop a comprehensive and integrated understanding of academic topics. When used as teaching practices, it is embodied in the educational methods that teachers adopt to enhance students' thinking skills from by applying the principles of biomimicry in classroom activities and practical experiments. Biomimicry can also be considered scientific content that can be integrated into educational curricula by including concepts and methods inspired by nature in lessons and courses, which contributes to developing students' awareness of environmental relationships and sustainable technological applications. That is, the uses of biomimicry in education vary depending on the context and educational objectives. This makes it a flexible and valuable educational tool to promote effective and comprehensive learning. However, the current study is interested in defining biomimicry as a reliable teaching model in science education and interdisciplinary education through the application of biomimicry to learn design thinking skills.

By extrapolating the literature analyzed by the study, the biomimetic teaching model can be defined as ***"an educational and learning framework based on biomimetics that aims to enhance learners' design thinking skills through integrated stages with specific steps and procedures, by employing scientific activities that depend on learners' observation of shapes, functions, structures and processes. And use materials that have evolved in nature as a point of inspiration to make their designs to confront human problems in the context of science education and interdisciplinary education."***

The biomimetic model can be used in teaching to combine several disciplines, namely science, technology, engineering, mathematics, arts, and other subjects that can be integrated to explore solutions to a problem, especially sustainability problems. The use of biomimicry is not only limited to developing design thinking skills but is also used to develop many skills such as cognitive and scientific skills, twenty-first-century skills, soft skills, sustainable thinking, critical and creative thinking, and others.

Methods for Learning Biomimicry in the Classroom

Biomimicry can be applied in teaching and learning in many ways (Eagle-Malone, 2021; Yeter, et al, 2023; Deliman & Lott, 2023; EcoRise, 2024). Here are some examples:

1. **Collaborative and Interdisciplinary Learning:** Biomimicry focuses on the importance of cooperation and interconnectedness in natural ecosystems. Educators can design interdisciplinary projects and activities by promoting collaboration, learners can combine their diverse skills and perspectives to provide comprehensive and innovative solutions to real-world problems and motivate learners to explore how nature may have already solved similar problems. This entry stimulates creativity and research and fosters an appreciation for the wisdom of nature.
2. **Sustainable Learning and Sustainability:** Nature is inherently sustainable, with many ecosystems having the ability to regenerate and self-heal. Educators can benefit from these principles to guide learners in designing and developing solutions that reduce negative environmental impacts and support regenerative practices, thus contributing to the promotion of sustainable practices.
3. **Learning outside the Classroom:** Biomimicry often begins with wonder and curiosity about the natural world. Teachers can encourage this outlook by incorporating out-of-class and observational learning experiences into the learning process. This method sparks a desire for lifelong learning and a deep appreciation for the natural environment.

4. **Incorporating Nature's Designs and Patterns:** Nature provides a variety of designs and patterns that have evolved over the years. Teachers can incorporate these designs into learning environments to stimulate creativity and critical thinking in learners. For example, geometry lessons could explore the efficient hexagonal pattern found in honeycomb cells or the dynamic structure of bird wings to understand engineering and design principles. The natural ecosystem is also an excellent model of interconnected and adaptive systems. Educators can utilize these examples to teach learners about sustainable resource management.

5. **Discovery Learning through Picture Books:** A study (Deliman & Lott, 2023) stated that biomimicry is a field of engineering that uses nature to design solutions to human problems and challenges. For young students to understand this complex phenomenon, they need opportunities to explore, ask questions and discuss ideas about solutions inspired by nature. Although direct scientific experiments with biomimicry would be ideal, this may not always be practical and is costly in time and effort, but elementary teachers can bring this phenomenon into the classroom using picture books. Picture books create the context in which students ask questions, identify problems, and develop potential solutions using core competencies found in the Next Generation Science Standards (NGSS). Picture books for children are engaging and can spark curiosity and creativity that spill over the pages of the book.

Prerequisites for Learning Biomimicry

Effectively implementing the biomimicry approach in educational settings requires enhancing teachers' understanding and competence through targeted professional development programs, both during their initial training and through ongoing in-service training focused on practical application. By training teachers in the principles and levels of biomimicry, enabling them to effectively integrate nature-inspired learning experiences into their educational practices. This allows teachers to guide students in recognizing the ingenuity and wisdom of nature, extracting valuable lessons from natural systems, strengthening connections between different disciplines, and improving creative problem-solving and critical thinking skills (Adıgüzel, et al, 2024).

As ***Deliman & Lott (2023)*** point out, understanding biomimicry requires students to have a basic understanding of inventions. If students are not familiar with inventions, the teacher should introduce biomimicry by having students learn about the inventions around them. The teacher may ask a student to come to the board and write their name but do not give them a dry-erase marker. The student will realize that he or she cannot write on the board without a dry-erase marker. The teacher will then introduce the word invention, something that has been made and can solve the problem. In this case, a dry-erase marker is an invention for writing on a whiteboard. The teacher can then ask students to search the class for other inventions (e.g. computers, pencil sharpeners, etc.). Teachers should emphasize that inventions do not have to be electronic but can be as simple as tissues or bandages.

Steps to Implement Biomimetic Activities in the Classroom

Biomimicry is a concept that is difficult for young children to understand, so William, et al (2018) suggested steps for classroom activities that rely on biomimicry in classrooms for young learners at the lower stage, as follows:

1- The activity begins with a class discussion about camouflage, a concept that many students have experienced.

2- Students participate in an activity in which they are asked to quickly collect colored dots from a piece of construction paper.

3- Students are introduced to Velcro through a story about "Velcro"[1].

4- Reintroducing the term biomimicry and defining it clearly.

5- Pupils research their biomimetic idea Pupils are asked to research an observation in nature that might have some practical use for humans.

[1] In 1941, Swiss engineer Georges de Mestral was on a hunting trip with his dog in the Swiss Alps. De Mestral noticed that burdock seeds (a type of wild plant) stuck strongly to his clothes and his dog's fur and decided to develop a synthetic material that mimicked this mechanism. Eventually, he was able to produce two ribbons: one with hooks and the other with loops that could be tightly intertwined together. He called his invention "Velcro".

6- Create a short presentation incorporating their findings by using resources from the Biomimicry Institute's Ask Nature[2] website.

7- Throughout this activity, students work collaboratively in groups of four in a heterogeneous manner, paying attention to reading, creativity, expression, and communication skills.

An Example of Using Biomimicry in a Science Lesson

EcoRise is published in collaboration with the Biomimicry Institute (EcoRise Youth Innovations & Biomimicry Institute, 2016). A collection of courses showing how to integrate and use biomimicry in education across different disciplines. We review the following example:

Lesson topic: Study of the biological adaptations of desert beetles in collecting water vapor from the air and their application in designing artificial devices to capture dew (fog).

The objective of the lesson:

- *Biological learning*: understanding the biological adaptations that help organisms survive in extreme environments.
- *Design thinking:* applying biological knowledge to engineering designs to solve human problems.
- *Practical experience:* Develop practical work skills through designing, building, and testing prototypes.

Lesson steps:

1. Exploring beetle adaptations:

- Physical Adaptations: Students learn about the physical structure of desert beetles that helps them collect water vapor from the air.
- External structure: such as wrinkled surfaces and ridges that help condense water from the fog.

[2] https://asknature.org/resource/what-is-biomimicry/

- Behavioral adaptations: Students learn about the behaviors that beetles use to survive, such as standing at a certain angle to catch as much dew as possible.
- Case studies: Examine detailed examples of beetle adaptations through illustrative photos or videos.

2. Examples of human innovations:

- Innovations inspired by nature: Study several examples of human innovations that take advantage of beetles' strategies for collecting water.
- Fog capture nets: such as nets used in dry areas to collect water from fog.
- Condensation technologies: applying designs inspired by the surface of beetles to develop materials and devices capable of condensing and collecting water.

3. Design and construction of a dew catcher model:

- Introduction to the practical project: explaining the purpose of the project and how to apply the knowledge gained from studying beetles.
- Construction materials: Provide a list of materials and tools needed to design and build the dew catcher, such as mesh fabric, plastic, and metal frames.
- Design: Guide students to draw diagrams and designs for their prototypes, considering the principles they learned from the beetles.
- Construction: Work on building the prototype of the dew catcher, using available materials.
- Testing and Evaluation: Testing models in simulated dew collection conditions, and evaluating their effectiveness based on the amount of water collected.

It is clear from the previous lesson that the theoretical and practical aspects are combined. This helps students develop their analysis and design skills and encourages them to think about how to use knowledge derived from nature to develop innovative and sustainable solutions to the challenges facing humans.

Benefits of Integrating Biomimicry into Education

Using a biomimetic approach in education provides many benefits (MacKinnon, et al. 2020; Deliman & Lott, 2023; Yeter, et al, 2023; Eagle-Malone, 2021), including:

1. **Sustainability**: Biomimicry promotes awareness of sustainable designs found in nature. By learning from ecosystems and respecting ecological balance, learners develop a stronger awareness of environmental conservation and an inclination to adopt sustainable practices in their personal and professional lives.
2. **Interdisciplinary education:** Biomimicry links different disciplines such as biology, engineering, design, technology, chemistry, physics, and the arts. It encourages an interdisciplinary approach to problem-solving, which helps learners recognize the interconnectedness and integration of knowledge.
3. **Problem-solving and critical thinking**: Biomimetics enhances problem-solving and critical thinking skills. Learners are encouraged to analyze and adapt nature's strategies to human contexts, evaluate the efficacy of natural models, and apply them in different fields such as technology, engineering, and design.
4. **Innovation and creativity:** Biomimicry promotes innovation and creativity by motivating learners to observe and understand natural systems. Learners are motivated to think creatively and develop innovative solutions to real challenges.
5. **Lifelong learning:** Biomimicry promotes continued learning by fostering interest in the knowledge available in nature. Students are encouraged to explore and benefit from the natural world after formal education, which motivates them to continue learning.
6. **Relevance to the real world:** Biomimicry emphasizes the practical application of knowledge. By studying nature's solutions and translating them into tangible innovations, students see applied relevance to their learning, leading to a more meaningful and impactful learning experience.

7. **Adaptation and resilience:** Biomimicry teaches learners valuable lessons about resilience and adaptation by studying the abilities of organisms to adapt to changes. Learners are equipped to face challenges with confidence and flexibility, enabling them to adapt to changes in the future.

Challenges in Integrating Biomimicry into Education

The most important challenges facing the integration of biomimicry into general school curricula, interdisciplinary curricula, and science curricula can be deduced through an analysis of what was reported in the studies of (Oguntona & Aigbavboa, 2023a; Yeter, et al, 2023; Deliman & Lott, 2023) as follows:

1. **Lack of interdisciplinary approaches:** Biomimicry requires an interdisciplinary and integrated approach. It cannot be implemented effectively by focusing only on one specialty. It also requires a comprehensive understanding of concepts and principles from different fields such as biology, design, engineering, and sustainability. Teachers need to collaborate with experts from different fields to expose students to a wide range of opinions and facts.

2. **Resistance to change:** Resistance to change within educational institutions may hinder the adoption of a new pedagogical approach such as biomimicry. Some administrators and teachers may be reluctant to abandon traditional educational methods or may view biomimicry as a passing trend rather than a viable educational strategy. Overcoming this resistance requires building awareness, developing skills, and changing mindsets.

3. **Lack of awareness and knowledge**: Lack of understanding and awareness of biomimicry principles among teachers is another major challenge. Many teachers may be unfamiliar with the concept or the potential benefits of improving the learning experience. Without sufficient knowledge and strong biomimicry thinking ability by teachers, it is difficult to effectively integrate biomimicry into the curriculum.

4. **Lack of resources and difficulty in accessing information**: Implementing biomimicry for education faces challenges due to lack of resources and difficulty in accessing relevant information. Teachers may have difficulty finding suitable materials, case studies, and examples of biomimicry in practical work that students will find useful. Limited access to biodiversity and natural environments may also be an obstacle to the application of biomimicry, as it relies heavily on direct observations of nature and its patterns.

5. **Rigid curricula:** Many educational institutions are characterized by rigid curriculum structures and standardized assessment requirements, leaving limited space to incorporate an innovative approach such as biomimicry. Integrating new teaching methods and content into existing curricula can be a challenge without disrupting the traditional framework followed by most schools and educational institutions.

6. **Lack of training and professional development**: To effectively implement biomimicry in education, teachers need the necessary training and knowledge to apply biomimicry principles in their classrooms. However, specialized training and professional development opportunities focused on biomimicry are often rare or unavailable, especially with the novelty of this approach.

Results of the Third Question:

The third question states **(What is the relationship between biomimicry and design skills?)** By referring to previous literature and studies, it was possible to answer the question as follows:

The relationship between biomimicry and design skills

Industrial designer Hastrich (2006) in collaboration with the Biomimicry Institute developed the spiral methodology for using biomimetics in design; This is to help innovators and designers use nature to arrive at designs to solve human challenges, as shown in the following figure:

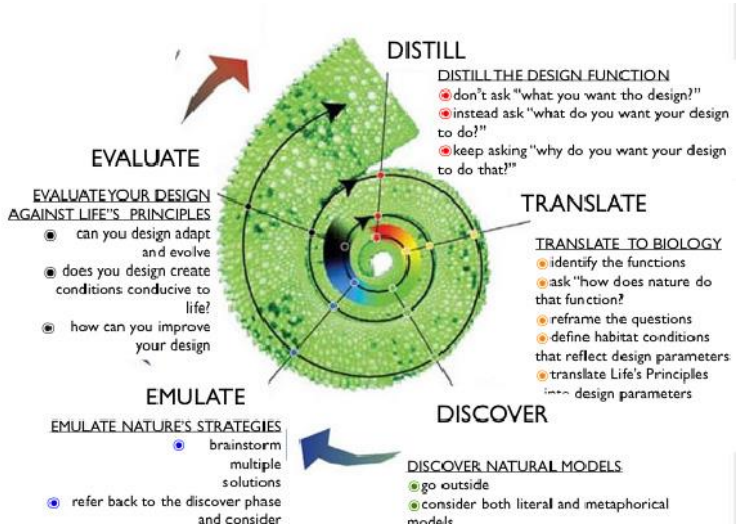


Figure (2): Steps for Using Biomimicry in the Design Process (Hastrich, 2006) in (Rossin,2010**)**

1- **Defining the problem:** Defining the function of the design. What do you want the design to do or what is its purpose? Not just design but the function of design. Thinking about design challenges from a different perspective reconceptualizing building with the environment. Begin by deconstructing the problem in terms of different functions, processes, solutions, and constraints, then ask how nature deals with each other individually; Begin to organize this analysis into a complete visual framework, exploring big concepts as starting points. Determine what causes the problem, who will be involved in the solution, where the problem is, and where the solution will be applied.

2- **Translation and extraction**: making a connection between the design problem and the natural world. Translating design into functions that can be implemented in nature. Ask how nature thinks about this function in sustainability solutions in the early stages of design. Determine habitat/location, climatic conditions, nutritional conditions, social conditions, and time conditions. As for abstraction, it means looking for patterns and recurring processes within nature that achieve success. Create a taxonomy of design principles. Choose the heroes (objects and systems) with the most relevant strategies for your design challenge and need. The bottom

line from this is to arrive at a set of achievements and recurring principles that achieve this. success. Study the relationships between materials, environment, performance, and design.

3- **Exploration:** Finding the best natural models to answer questions related to solving the design problem. Brainstorm your challenge with different disciplines such as biologists and mechanical engineering to include in your design. This is done through the Ask Nature website to give different biological solutions or knowledge and self-diligence, which is extremely difficult to reach solutions.

4- **Simulation:** Simulating the natural strategy, brainstorming many solutions, and returning to discover the part that needs a solution and considering it the final design, then making the conclusion and result in partnership with biologists and returning to the design and trying to discover many strategies.

5- **Evaluation:** Evaluating the design about the principles of nature in terms of: Can the design adapt and adapt? Does the design create conditions that adapt to life? Finally, evaluate how to improve the design.

According to (Blok, & Gremmen, 2016; Stevens, et al, 2017; Bianciardi, et al. 2021) biomimicry is an approach to design that seeks to find solutions by imitating patterns and strategies proven in nature. There are two main ways to apply biomimicry in design:

The first method: from challenge to biology

This approach begins by identifying a specific problem or challenge and then searching nature for solutions. The steps involved include:

A- Defining the challenge: formulating the problem. It may be an engineering challenge, a sustainability issue, or a design inefficiency.

B- Biological research: studying how nature solves similar problems. This requires studying organisms, ecosystems, and natural processes to understand their mechanisms and strategies.

C- Extracting principles: extracting the basic principles and strategies used by living organisms. This requires a deep understanding of biological processes and their translation into design principles.

D- Application in Design: Adapting and applying these biological principles to create innovative solutions to the original challenge. This step involves conceptualizing, prototyping, and testing designs to ensure they are effective in solving the problem.

Example:

- Challenge: Reducing energy consumption in buildings.
- Biological solution: Termite mounds maintain a stable internal temperature through natural ventilation.
- Application: Design of buildings with a passive cooling system inspired by the ventilation structure of termite mounds.

The second method: from biology to design

This approach begins with discovering a biological principle or strategy in nature and then searching for its applications in design. The steps involved include:

A- Biological discovery: the study and discovery of nature's mechanisms and strategies in living organisms and ecosystems.

B- Principles analysis: Analysis of the basic principles and strategies used in the organisms that were studied.

C- Visualizing the application: to think about how these biological principles can be applied in new designs. This includes creativity in using biological knowledge to improve or create new designs.

D- Design implementation: developing designs and applying biological principles to them. This step involves testing and improving models based on biological understanding.

Example:

- Biological detection: Gecko feet stick to surfaces through van der Waals forces.
- Principles Analysis: Understand how geckos use their tiny hairs to cling to surfaces.
- Visualize applications: Develop adhesives inspired by gecko feet.
- Design implementation: production of an adhesive tape that can be used in medical or industrial applications.

In the context of teaching and learning, Eagle-Malone (2021) notes that biomimetics, the process of using nature to guide and develop innovative thinking, is useful in helping students understand scientific concepts. Educators interested in incorporating biomimetic science into lesson plans may find that experiential learning in informal science institutions (ISIs) with natural models and exhibits is a valuable tool to accompany classroom learning. When visiting these institutions, students can observe nature in real time and immerse themselves in inspiration. As students explore these natural models in the environments and exhibits, teachers might ask students about interesting features they notice and prompt them to think creatively about innovative designs these features could inspire. For example, an elephant's trunk might inspire them with the idea of a robotic arm. These direct experiences in informal science institutions may tap into students' innate love of nature to learn more about living organisms and lead to increased creativity and design production.

Biomimicry Thinking is also defined as a design and creative methodology that draws inspiration from ideas and solutions from nature to solve human problems and improve processes, products, and services. This methodology is based on observing and understanding processes, systems, and structures found in nature and then mimicking them to achieve sustainable and innovative improvements. (Bianciardi, et al, 2017)

Qureshi's (2022) study explored how students engage in the biomimicry process and the types of designs they produce to reveal ideas that can help teachers teach biomimicry. This study was conducted on 70 university students who were divided into 12 groups. Using an inquiry-based learning approach, students chose their health challenge and proposed a design that mimics nature. The students provided reports that were analyzed through thematic analysis that revealed several findings, including the two most common forms of biomimicry carried out by the students. The study provided further insights into the "crossbreeding" strategy, the types of organisms the students mimicked, and the successes And the difficulties faced by students in applying biomimicry.

The study by Coban & Coştu (2023) was also interested in integrating biomimicry into science education by proposing a teaching approach for primary school students. The study used an action research approach, where the developed "biomimicry teaching approach" was applied in the fifth grade of primary school in a public school in Turkey, where one of the researchers works as a teacher. According to this approach, pupils are first introduced to different types of living organisms to enhance their ability to observe living organisms and understand the relationship between structure and function. Secondly, they were introduced to the concept of biomimicry through several examples. Finally, the students participated in the "Biomimetic Design Model". At the end of the biomimicry lessons, pupils designed their models through drawing and modeling inspired by living organisms. The effects of the "biomimicry teaching approach" on students' designs were analyzed. The results showed that fifth graders mostly produced design ideas inspired by the organisms presented during the biomimicry lessons. Pupils' attempts to create different designs inspired by living organisms in nature, taking into account the function behind the physical structure of these organisms, showed that pupils can produce creative and workable design ideas when they are introduced to the concept of biomimicry through the Introduction to Teaching Biomimicry.

Steps of Biomimicry Design Thinking

Design thinking is a style of thinking. This concept dates back decades and is the product of the accumulation of academic research and actual practice with continuous development. It relies on a mixture of sciences, the most important of which are architecture, engineering, humanities, and business administration. The design thinking methodology is based on solving real-life issues, exchanging opinions, innovating, and producing creative ideas.

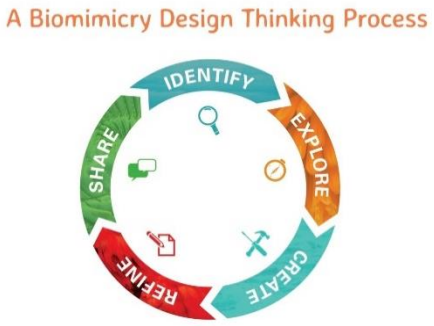


Figure (3): Steps of Biomimicry Design Thinking (EcoRise, 2024)

Design thinking is defined as a set of mental processes that learners practice, to solve real-life issues and problems by exercising imagination and the ability to define the problem, generate creative ideas, and produce and test prototypes ((ElBaz, 2018).

The EcoRise Foundation (2024) stated that the five main steps of the biomimetic process that rely on design thinking, as shown in Figure (2), are:

1- Identifies: Identify the challenge to be addressed, including stakeholders, criteria and constraints

2- Explores: Discover how nature has solved similar challenges

3- Innovate: Brainstorm design ideas that mimic nature's strategies.

4- Refine: Evaluate and improve the strongest design idea.

5- Share: Develop the materials needed to share your design solution with the world.

Thus, biomimicry is a useful way to develop student skills, such as design thinking and systems thinking, especially when complemented with inquiry-based learning (Qureshi, 2022).

The Relationship between Biomimicry and STEM Approach

Biomimicry, a discipline inspired by nature's time-tested strategies, has emerged as a promising model for innovation and problem-solving in various fields (Lurie-Luke, 2014). Biomimicry involves the idea that nature has already solved many of the challenges facing humanity. By studying and simulating natural shapes, strategies, processes, and ecosystems, learners can develop a deeper understanding of the world around them and apply this knowledge to create sustainable designs and solutions. This approach to education offers an interdisciplinary approach, blending life sciences, STEM subjects, and problem-solving in an integrated manner. Creative, design, and systems thinking (Yeter, et al, 2023)

Although biomimicry has a long history, it has only recently gained widespread interest in education. Biomimicry aims to draw inspiration from nature to solve problems and develop critical thinking skills. It is considered a design-oriented approach, based on biological sciences and engineering, and applied in fields such as materials science, architecture, and urban planning. The spread of STEM and STEAM approaches globally has strengthened the connection between them and the biomimetic approach. Biomimicry is sometimes combined with these approaches, as both focus on design and innovation. Although STEM education focuses on mathematics and science subjects, biomimicry requires a deep understanding of natural processes and the interaction between organisms and their environments. A study (Yıldırım, 2019) demonstrated that student science teachers have positive opinions about biomimicry practices in STEM education, and this in turn strengthens the connection between Those entrances.

It was pointed out by (Canbazoğlu-Bilici et al. 2021; Gencer et al, 2020) indicated that using the biomimetic approach in educational activities related to science, technology, engineering, and mathematics (STEM) can be effective in the processes of designing integrated projects that combine various disciplines. In addition, studies have shown that this approach can improve students' scientific research skills. For example, when students participate in biomimicry and STEM activities, they use

various resources such as books and documents, collect and interpret data, develop models, explain scientific concepts, and share and refine ideas through discussion with their peers. This enhances their ability to engage in the active learning process.

Results of the Fourth Question:

The first question states **(What is the teaching model that the study proposes for using biomimicry in developing design thinking skills?)** By referring to previous literature and studies, the question could be answered as follows:

The proposed Teaching Model Using Biomimicry to Enhance Design Thinking Skills

Many teaching models have emerged that help the learner face educational situations. The reliance on teaching models came from the premise that teaching is not considered an art. Not only as it was believed until recently, but it has become a science, meaning that it requires organized knowledge of its origins, methods, and strategies, and how to plan it, to achieve specific goals, and how to maintain active interaction with the learner, measure his progress towards achieving his goals, and determine the effectiveness of the teaching process in order to Improve their practice in the future.

Teaching models in the field of science education also form a basis for understanding scientific phenomena in innovative and interactive scientific ways. As models are conceptual frameworks based on the main philosophical orientations towards teaching and learning, they serve as guidelines that help teachers define their responsibilities during the planning, implementation and evaluation stages of teaching. It helps teachers help learners learn how to learn, enhance their understanding of science, and provide a comprehensive educational curriculum that focuses on building knowledge in an integrated, social, interactive manner. Effective models enable learners to acquire thinking skills, research, experimentation, and reasoning with evidence, which enhances their abilities to make appropriate decisions based on scientific knowledge. It enhances scientific culture and encourages innovation and discovery (Behar-Horenstein & Seabert, 2005; Joyce & Weil, Calhoun, 2000)

It is procedurally defined as: ***"an educational and learning framework based on the principles of biomimicry and aims to develop design thinking skills among learners through integrated stages with specific steps and procedures; by employing scientific activities that depend on learners' observation of the forms, functions, structures, processes, and materials that have evolved in nature and use them as a point of inspiration for work." Their designs to confront human problems in the context of science education and interdisciplinary education."***

The Theoretical Premises of the Model Based on Biomimicry:

The proposed model is based on many different research and theories, focusing mainly on how knowledge develops, how it is exchanged among individuals in a specific group, and how it benefits from the processes of thinking, communication, and social interaction to build models and designs to solve environmental and scientific challenges facing learners. This model was developed considering the following educational trends:

1- **Constructivism**: This theory emphasizes that learning is a process of constructing knowledge through experiments and experiences. In the context of biomimetic education, learners can explore biological systems and apply them to solve real problems, enhancing their understanding of scientific concepts.

2- **Piaget's conceptual change research:** Piaget's theory states that individuals go through successive stages of cognitive development in which their interpretation of the world changes. Conceptual change occurs when new information confronts old concepts with challenges and contradictions that require modification of beliefs. In biomimetic education, educational activities can be designed to match students' stages of cognitive development, enhancing their understanding of biological concepts. Piaget also believes that balance is an essential element in the development of learners' learning. When students encounter external disturbances or new information through biomimetics, they react to achieve cognitive balance. This interaction encourages them to modify their previous concepts and comprehend new concepts more deeply, and the teacher can organize educational

activities in a way that supports the correction and development of scientific concepts. This includes encouraging the learner's role in constructing his or her knowledge based on previous experiences, helping students make their ideas clear and guiding them toward a correct understanding of new concepts.

3- **Vygotsky's Theory "Social Development Theory":** which focuses on the vital role of social interaction in the development of cognition. Vygotsky placed what is called the Zone of Proximal Development (ZPD). This idea refers to the difference between what the learner can achieve on his own and what he can achieve with the help of others. In biomimetic education, teachers can use ZPD to identify activities that are within students' capabilities and support them to achieve greater understanding through interaction and guidance. Vygotsky also stressed that learning occurs through interaction with others. In the context of biomimicry, students can work together in groups to solve problems and design projects, which promotes collaborative learning and the exchange of ideas.

Limits of the Proposed Model:

1. Curriculum: The model can be applied in science education as well as multidisciplinary education by integrating several disciplines, namely science, technology, engineering, mathematics, environment, arts, and other subjects that can incorporate to explore solutions to a problem, especially sustainability problems, through the biomimicry teaching model.

2. Educational stage: The model, with its various stages, is suitable for learners at all educational stages, from the primary stage to the secondary and university levels. However, considering the selection of problems or challenges to suit the age and cognitive level of the students, grading from simple to more complex according to the nature of the age stage.

At the primary level, the focus can be on simple problems, using direct examples from the environment around the pupils that require simple and formal modeling skills. As for the preparatory stage, more complex challenges can be presented, requiring deeper analysis, greater understanding of scientific concepts, and the design of more functional models. At the high school and university levels, you can

delve deeper into complex challenges that require the use of advanced design skills. In addition, the teaching model must include flexibility in educational methods and activities to meet the different needs and preferences of learners, with an emphasis on providing continuous support and guidance by the teacher to ensure that learners progress and achieve the desired learning goals.

Objectives of the Proposed Model:

The model contributes to achieving the following goals:

1- Highlighting the challenges facing education at the present time, the forefront of which is enabling innovative and effective educational methods to stimulate learners' interest in scientific subjects and develop their scientific and thinking skills.

2- Educating learners about the importance of studying the nature of biomimicry in their daily lives, its impact on solving human challenges, and its effective role in achieving sustainability in various fields such as energy, technology, health, and others.

3- Enabling learners to build their knowledge about the concept of biomimicry, its levels and principles, and ways to employ them in solving challenges facing society, through discussion-based interaction and scientific communication.

4- Explain the importance of the teacher's role in implementing the proposed model, and how it can motivate learners and direct them towards building designs and models that solve environmental problems and challenges in their real world.

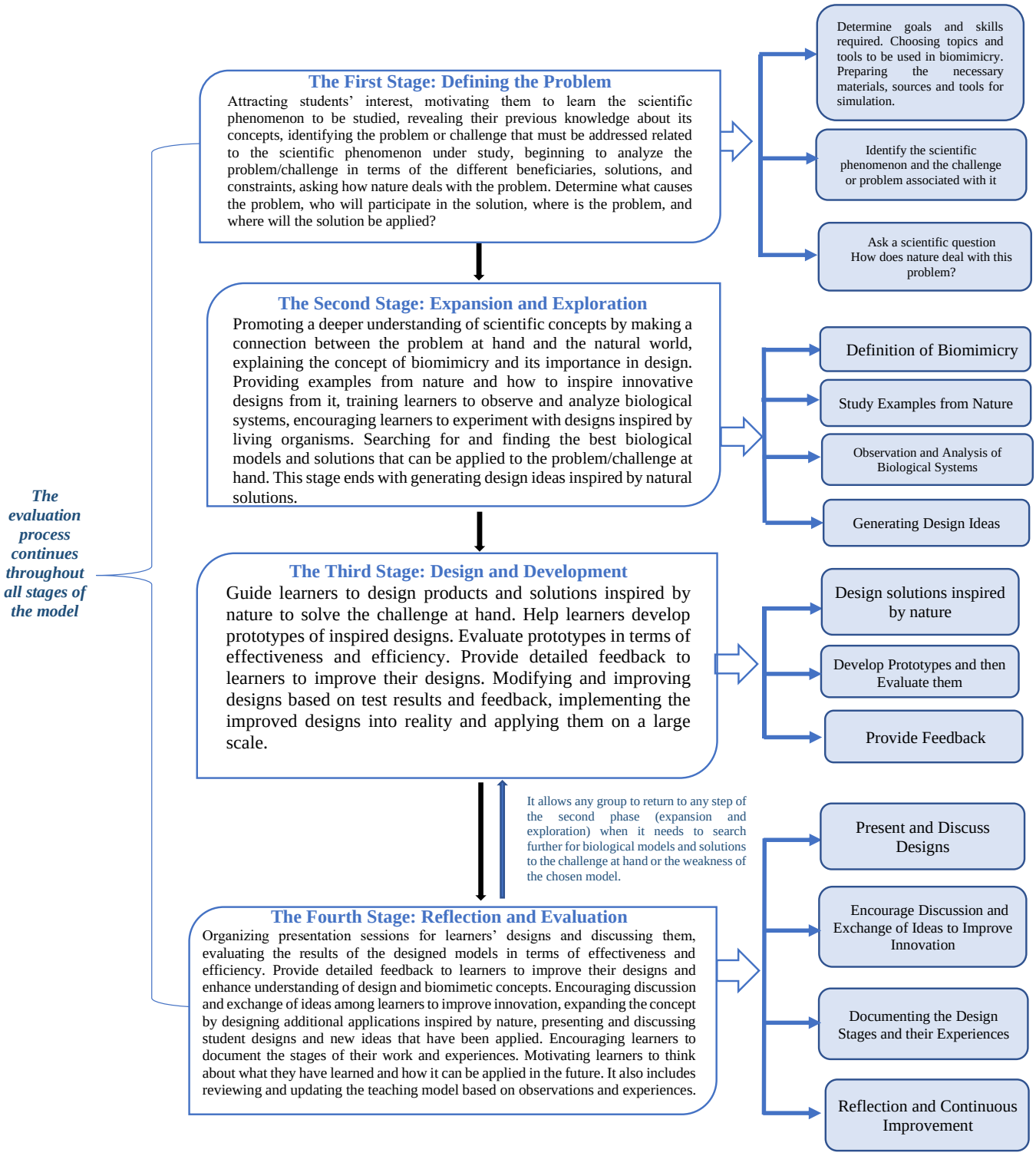
5- Supporting the concept of conceptual change among learners, through the gradual stages of the model, considering the guidelines followed for the success of each step of the model.

6- Learners practice engineering design skills of asking questions, defining problems, using mathematics and computational thinking, constructing explanations and designing solutions, developing possible solutions, and improving design solutions.

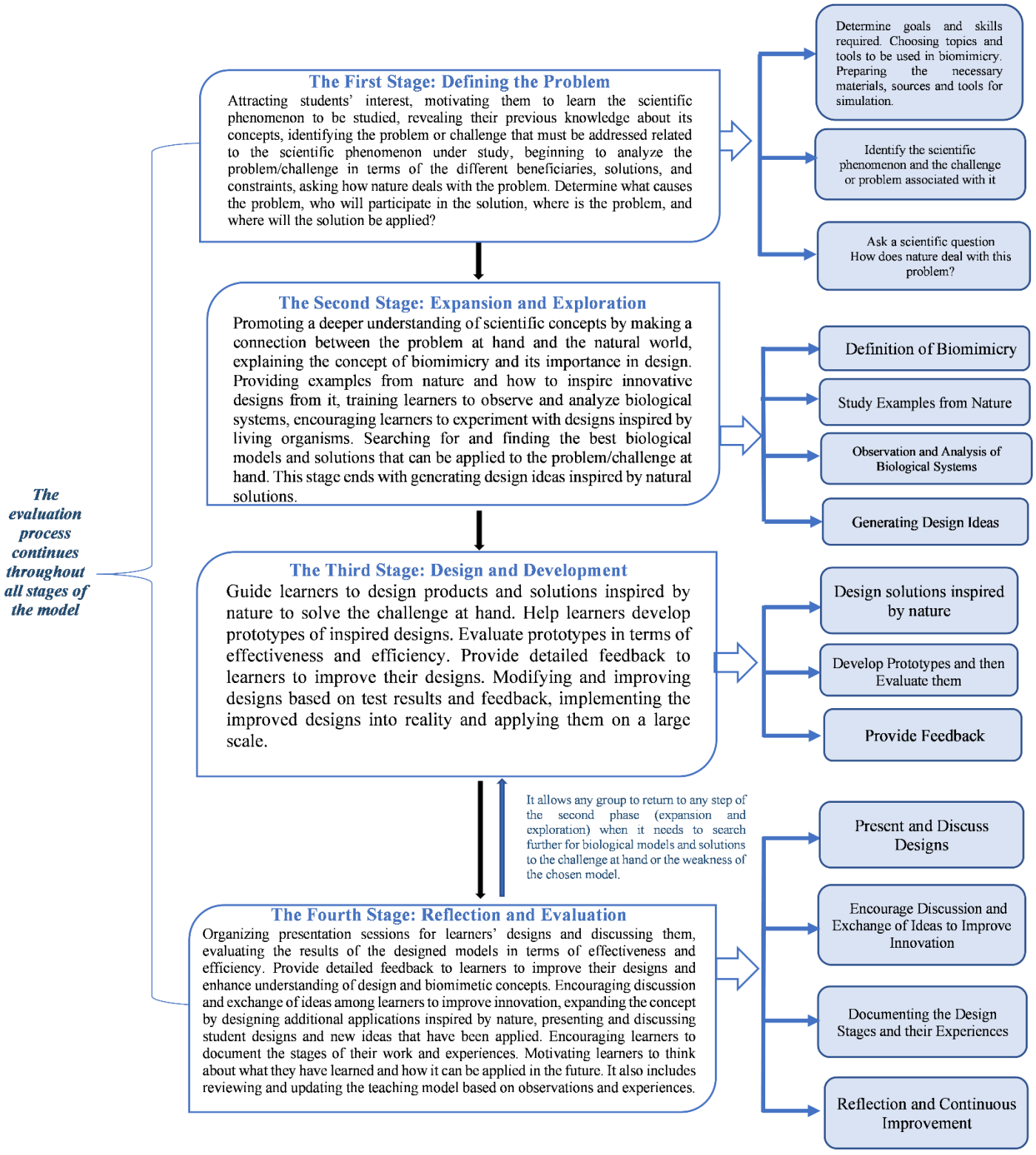
7- Developing learners' design thinking skills, such as empathy, definition, idea generation, model building, and testing.

8- Enhancing and developing verbal communication among learners by using language as an important tool of thinking, during social interaction among them.

The following is the proposed teaching model based on biomimicry to develop design skills:



The following is the proposed teaching model based on biomimicry to develop design skills:



Steps to apply the proposed teaching model (the role of the teacher in applying the stages of the model)

The first stage: Defining the problem

Educational needs analysis includes determining educational goals and required skills. Selection of educational materials: Selection of topics and tools to be used in biomimicry. Preparing the educational environment: preparing the necessary materials, resources, and tools for the biomimicry. Attracting students' interest, motivating them to learn the scientific phenomenon to be studied, revealing their previous knowledge about its concepts, identifying the problem or challenge that must be addressed related to the scientific phenomenon under study, beginning to analyze the problem/challenge in terms of the different beneficiaries, solutions, and constraints, asking how nature deals with the problem. Determine what causes the problem, who will participate in the solution, where is the problem, and where will the solution be applied?

The teacher's role in the first stage (identifying the problem) can be explained as follows:

- The teacher begins to attract students' attention by presenting an interesting scientific problem or phenomenon related to biomimicry.
- Visual materials or practical experiences can be used to make the topic more realistic and tangible.
- The teacher encourages students to think critically about the phenomenon by asking stimulating questions and presenting thought-provoking scenarios.
- Uses storytelling techniques or real-life examples to illustrate the importance of the problem to be solved.
- The teacher asks probing questions to uncover what students already know about a scientific phenomenon.
- Brainstorming sessions or mind maps can be used to synthesize students' ideas and prior knowledge.

- The teacher helps students identify the challenge or problem to be studied by directing them to the main elements of the problem.
- The teacher shows examples of how to address problems similar in nature.
- The teacher supervises the process of analyzing the problem by the students in terms of potential beneficiaries, possible solutions, and various constraints.
- The teacher directs the discussion towards thinking about how nature deals with this problem and applying nature's principles to solve it.

The second stage: Expansion and exploration

Promoting a deeper understanding of scientific concepts by making a connection between the problem at hand and the natural world, explaining the concept of biomimicry and its importance in design. Providing examples from nature and how to inspire innovative designs from it, training learners to observe and analyze biological systems, encouraging learners to experiment with designs inspired by living organisms. Searching for and finding the best biological models and solutions that can be applied to the problem/challenge at hand. This stage ends with generating design ideas inspired by natural solutions. The Ask Nature website can be used to provide various biological solutions.

The teacher's role in the second stage (expansion and exploration) can be explained as follows:

- The teacher provides a comprehensive and detailed explanation of the scientific concepts related to the problem at hand.
- Explains the relationship between the problem and the natural world through illustrative examples and case studies.
- The teacher explains the concept of biomimicry and how solutions can be inspired by biological systems.

- Uses real-life examples to explain how nature-inspired designs have led to innovative and effective solutions.
- Shows various examples of how innovative designs can be inspired by nature.
- This can include visual presentations, videos, and demos.
- Organizes practical and field activities to train students in observing and analyzing biological systems.
- Encourages the use of scientific instruments and careful observation techniques to document observations.
- The teacher encourages students to experiment with designs inspired by living organisms.
- Provides the necessary resources and support for students' experiences and encourages them to innovate.
- Directs students to search for biological models and solutions that can be applied to the problem at hand.
- Supervises the research process and provides the necessary scientific sources and references.
- Facilitates design idea generation sessions inspired by natural solutions.
- Uses techniques such as brainstorming and group discussions to generate creative ideas.

The third stage: Design and Development

Guide learners to design products and solutions inspired by nature to solve the challenge at hand. Help learners develop prototypes of inspired designs. Evaluate prototypes in terms of effectiveness and efficiency. Provide detailed feedback to learners to improve their designs. Modifying and improving designs based on test results and feedback, implementing the improved designs into reality and applying them on a large scale.

The role of the teacher in the third stage (design and development) can be explained as follows:

- The teacher guides students in the process of transforming ideas into practical designs.
- Provides guidance on how to use biological principles in innovative designs.
- Provides resources and tools for developing prototypes.
- Provides technical support and practical advice during the model building process.
- Evaluates prototypes with students in terms of effectiveness and efficiency.
- Uses specific criteria to determine the strengths and weaknesses of models.
- Provides detailed feedback to each student or group on prototypes.
- Explains the areas that need improvement and how to achieve this.
- Guides students in the process of modifying and improving designs based on test results and feedback.
- Encourages students to experiment and modify frequently to arrive at an improved design.
- Helps in implementing improved designs and implementing them on a large scale.
- Supervises the process to ensure it is carried out correctly and efficiently.

The fourth stage: Reflection and Evaluation

Organizing presentation sessions for learners' designs and discussing them, evaluating the results of the designed models in terms of effectiveness and efficiency. Using the seven principles of biomimicry. Provide detailed feedback to learners to improve their designs and enhance understanding of design concepts

And biomimicry. Encouraging discussion and exchange of ideas among learners to improve innovation, expanding the concept by designing additional applications inspired by nature, presenting

and discussing student designs and new ideas that have been applied. Encouraging learners to document the stages of their work and experiences. Motivating learners to think about what they have learned and how it can be applied in the future, reviewing and updating the teaching model based on observations and experiences.

The teacher's role in the fourth stage (reflection and evaluation) can be explained as follows:

- The teacher organizes sessions to present the designs created by the students.
- It provides a platform for students to present their work and discuss it with their peers.
- The teacher evaluates models for effectiveness and efficiency using specific criteria and using the seven principles of biomimicry.
- Provides comprehensive feedback on the performance of each model and design.
- The teacher provides detailed feedback on the designs, including strong points and areas that need improvement.
- Uses feedback to enhance deep understanding of design and biomimetic concepts.
- Encourages students to discuss their designs and exchange ideas with classmates.
- Organizes discussion sessions to exchange ideas and suggestions to improve innovation.
- Stimulates students to think about additional applications inspired by nature.
- Provides new challenges to apply concepts they have learned in new contexts.
- Presents students' ideas and new designs for discussion and evaluation.
- Students are encouraged to provide feedback and opinions on the presented designs.
- Students are encouraged to document all stages of their work and experiences.
- Provides templates for documenting work in a systematic and organized manner.

- Encourages students to think about how they can apply what they have learned in future projects.
- Asks guiding questions to help students think about future applications of the knowledge they have acquired.
- The teacher collects feedback from students about the overall learning experience.
- Uses this feedback to update and improve the teaching model for the future.

Recommendations:

1. Using the teaching model proposed by the study for experimentation through a pilot study to prove its effectiveness or not in developing design thinking skills.
2. The need for developers and implementers of interdisciplinary curricula at the primary level to pay attention to using biomimicry in an attempt to link several disciplines as these curricula aim.
3. Including the content of the science curriculum across the various levels, as well as the biology, physics, and chemistry curricula, in biomimetic lessons, which contributes to developing engineering design skills and improving students' scientific and engineering practices, which is one of the three dimensions of science education for the next generation, as mentioned in the NGSS standards.
4. The need for programs to prepare and train science teachers, interdisciplinary curriculum teachers, and STEM teachers to pay attention to the study of biomimicry as one of the modern educational trends that can be used as a method of teaching and also as an input to enhance students' skills required in the twenty-first century.

Suggested Research:

1- The effectiveness of a teaching model based on biomimicry in developing design thinking skills among secondary school students in biology/chemistry/physics/geology and the environment.

2- A proposed vision for including biomimicry in science curricula in the middle school.

3- Evaluating the educational content provided in STEM schools in light of the biomimicry approach.

4- The effectiveness of educational activities based on biomimicry to develop model-building skills for primary school students in the multidisciplinary “Discover” curriculum.

5- A proposed program based on biomimicry to develop teaching practices related to the field of engineering design among pre- and in-service science teachers.

References:

- Abdul-Wahab, A., Bashandy, S., El-Barmelgy, H. (2022). A Systematic Framework for Activating the Definition of "Regenerative" Urban Design using "Bi o-mimicry Technology" as a Sustainable Environmental Approach to the Egyptian Urbanism. *Journal of Urban Research*, 46(1), 24-46. doi: 10.21608/jur.2022.117530.1086
- Adıgüzel, O. C., Küçükkayhan, S., Kürüm Yapıcıoğlu, D., Atik Kara, D. (2024). The effects of Teaching Practices Based on Biomimicry Approach on Learning-Teaching Processes. Participatory Educational Research, 11(3), 109-125. https://doi.org/10.17275/per.24.37.11.3
- Behar-Horenstein, Linda S & Seabert, Denise M. (2005) : Educational Practice and Theory, 27 (1), 49-66.DOI: https://doi.org/10.7459/ept/27.1.04
- Benyus, Janine M., (2002). Biomimicry: Innovation Inspired by Design, 2nd Edition, New York: Harper Perennial.
- Bianciardi, A., Credi, C., Levi, M., Rosa, F., & Zecca, (2017). A. Biomimicry thinking: methodo-logical improvements and practical implementation. Bioinspired, Biomimetic and Nanobi-omaterials, 6(2), 87-101
- Biomimicry Institute (2024) “BIOMIMICRY TOOLBOX" Your guide to applying nature’s lessons to design challenges.,”. https://toolbox.biomimicry.org/introduction/
- *Biomimicry3.8 (2013). The Biomimicry Life Principles* -, https://biomimicry.net/
- Blok, V., & Gremmen, B. (2016). Ecological innovation: Biomimicry as a new way of thinking and acting ecologically. *Journal of Agricultural and Environmental Ethics*, 29, 203-217.
- Canbazoğlu-Bilici, S., Mehmet Ali Küpeli, M. A.&S. Selcen Guzey, S. S. (2021). Inspired by nature: an engineering design-based biomimicry activity. Science Activities, 58:2,77-88, Doi:10.1080/00368121.2021.1918049

- Coban, M., & Coştu, B. (2023). Integration of biomimicry into science education: biomimicry teaching approach. Journal of Biological Education, 57(1), 145–169. https://doi.org/10.1080/00219266.2021.1877783
- Deliman, A., & Lott, K. (2023). Inquiry-Based Learning on Biomimicry. Science and Children, 60(6), 20–24. https://doi.org/10.1080/00368148.2023.12315919
- Eagle-Malone, R. S. (2021). Biomimicry outside the Classroom. *The American Biology Teacher*, *83*(2), 120-124.
- EcoRise (2024). Biomimicry and Science, https://www.ecorise.org/portfolio/biomimicry-and-science/
- EcoRise Youth Innovations & Biomimicry Institute (2016). Biomimicry and Science: Applying Nature's Strategies. https://www.ecorise.org/wp-content/uploads/2020/07/2_Welcome-and-Content-Overview.pdf
- ElBaz, M .(2018).The Effectiveness of A Training Program in STEM Education to Develop the Depth of Knowledge, Teaching Practices, and Design Thinking of In-Service Science Teachers, *Journal of the Faculty of Education, Assiut University* 34 (12), 1-5.
- Fahmy, S. (2018). Biomimicry as an Innovation in Modern Architecture Design. Journal of Architecture, Art & Humanistic Science, 3(10-2), 84-104. DOI: 10.12816/0044834.
- Gencer, S. A., Doğan, H.&Bilen, K. (2020). Developing biomimicry STEM activity by querying the relationship between structure and function in organisms. Turkish Journal of Education, 9(1), 64-105. Doi:10.19128/turje.643785
- Hastrich, Carl, (2006). "The Biomimicry Spiral," Biomimicry Newsletter, The Biomimicry Guild, Vol. 4.1 http://biomimicry.typepad.com. newsletter/files/biomimicry_newsletter_v4.pdf.

- Ilieva, L., Ursano, I., Traista, L., Hoffmann, B., & Dahy, H. Biomimicry as a sustainable design methodology—Introducing the 'Biomimicry for Sustainability frame-work. Biomimetics, 7(2), 37 (2022).
- Joyce, B. R., Weil, M., & Calhoun, E. (2000) Models of Teaching. Sixth edition. Needham Heights, MA.
- Lurie-Luke, E. (2014). Product and technology innovation: What can biomimicry in-spire? *Biotechnology Advances*, 32(8), 1494-1505.
- MacKinnon, R. B., Oomen, J., & Pedersen Zari, M. (2020). Promises and presuppositions of bio-mimicry. Biomimetics, 5(3), 33.
- Mejía-Villa, A., Torres-Guevara, L. E., Prieto-Sandoval, V., Cabra, J., & Jaca, C. Training for Sustainability through Biomimicry and Creative Problem-Solving Processes. Thinking Skills and Creativity, 101359 (2023).
- Oguntona, O., & Aigbavboa, C. (2023a). Nature inspiration, imitation, and emulation: Bio-mimicry thinking path to sustainability in the construction industry. Frontiers in Built En-vironment, 9, 1085979.
- Oguntona, O., & Aigbavboa, C. (2023b). Biomimicry Lessons for Teaching and Learning in Higher Education. *In Proceedings of the 10th Focus Conference (TFC 2023)* (pp. 172-183). Atlantis Press.
- Qureshi, S. (2022). How students engage in biomimicry. Journal of Biological Education, 56(4), 450–464. https://doi.org/10.1080/00219266.2020.1841668
- Roobeek, M. (2019). Biomimicry in the classroom how biomimicry can be integrated in the Dutch curriculum. Accessed from: https://biolearn.eu/wp-content/uploads/2019/12/Research-Report-Matthijs-Roobeek-How-Biomimicry-can-be-integrated-in-the-Dutch-curriculum.pdf on 14.11.2021
- Rossin, K.J. (2010). Biomimicry: nature's design process versus the designer's process. WIT Transactions on Ecology and the Environment. *Design and Nature* , 138, 559- 570.

- Snyder, H. (2019). Literature review as a research methodology: An overview and guide-lines. *Journal of Business Research*, 104, 333-339 .
- Stevens, L., Kopnina, H., Mulder, K. ,De Vries. M. (2021). Biomimicry design thinking education: a base-line exercise in preconceptions of biological analogies. *Int J Technol Des Educ* 31, 797–814 https://doi.org/10.1007/s10798-020-09574-1
- William J. Sumrall, Kristen M. Sumrall & Hannah A. Robinson (2018) Using Biomimicry to Meet NGSS in the Lower Grades, Science Activities, 55:3-4, 115-126, DOI: 10.1080/00368121.2018.1563041
- Yeter, I. H., Tan, V. S., & Le Ferrand, H. (2023). Conceptualization of Biomimicry in Engineering Context among Undergraduate and High School Students: An International Interdisciplinary, Exploration. *Biomimetics*, *8*(1), 125. https://doi.org/10.3390/biomimetics8010125.
- Yıldırım, B. (2019). The Opinions of pre-service science teachers about biomimicry practices in STEM education]. *Gazi University Journal of Gazi Educational Faculty*, 39 (1), 63-90. Accessed from: https://dergipark.org.tr/tr/download/article-file/674310