Biomimicry Design for Sustainability Skills in VET

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KA220-VET - Cooperation Partnerships in Vocational Education and Training

WP2 Biomimicry Process Design for Sustainability Skills

Project-Based Learning Framework through Biomimicry Process Design

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1. Introduction

Biomimicry, or "innovation inspired by nature", is based on the idea that nature has already solved the problems humans face today such as energy, transportation, food production, waste management and cooperation (Benyus, 2014). It follows the fundamental principles of nature, such as manufacturing renewable energy sources, using energy efficiently, recycling, and producing eco-friendly materials. Mimicking nature's principles and designs is significant in creating a sustainable world for the future of our planet. Furthermore, the 21st-century design of a sustainable future combines different disciplines through collaboration and cooperation methods.

Biomimicry is also in line with the objectives of STEM education by creating opportunities for teachers to teach STEM subjects and environmental sciences and to develop 21st-century skills. Thus, biomimicry does not only offer a method to learn from the natural world heritage to solve human problems, but also aims to educate nature lover and environmentally conscious students (Biomimicry Institute, 2017, p.3). As the global community faces complex environmental and societal challenges, designers and engineers look to the natural world for inspiration to create efficient, sustainable, and resilient solutions. Integrating biomimicry into educational curricula fosters creativity and problem-solving skills and instils a deep respect for nature and its processes.

There are a large number of VET graduates working in various economic areas. Many employment sectors are regulated by standards covering their operations, and many jobs have defined skills standards. Individuals typically undertake VET to obtain the skills level or qualifications needed for regulated occupations or jobs for which standards of competence levels of skills required are established. Unfortunately, many existing regulations and standards date from an era before the need for sustainability was fully comprehended and have not yet been updated in-depth to meet the requirements for a transition to a green economy. They may even help maintain a "business-as-usual" mode of operations, work processes and methods when this is not sustainable, using

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raw materials and creating waste and emissions to a degree that causes unnecessary environmental harm.

Implementing education for sustainable development (ESD) in VET can serve as an enabler of transformation in (T)VET institutions by enhancing the sustainability scope of an institutional vision and increasing opportunities to build the capacities of the community and stakeholders in it. In effect, ESD in VET provides an enhanced tool to equip youth and adults with the skills needed in the changing world of work, including the knowledge and competency requirements to transition to green economies and societies.

In this context, blending Biomimicry Process Design and Project-Based Learning (PBL) emerges as an effective pedagogical strategy that aligns perfectly with the principles of biomimicry. PBL engages students in real-world projects that require critical thinking, collaboration, and hands-on learning. By working on projects that address genuine challenges, students develop a deeper understanding of the subject matter and gain practical skills directly applicable to their future careers.

This document elaborates a constructive framework for incorporating biomimicry into a PBL environment to build green and problem-solving skills that are in demand by industry and society. The LET'S MIMIC framework defines the desired learning outcomes, including the knowledge, skills, and competencies students are expected to acquire. It also outlines specific learning activities and assessment strategies, ensuring a comprehensive and coherent approach to teaching and learning.

This document provides a detailed blueprint for teachers and curriculum developers to facilitate the effective implementation of PBL in biomimicry design projects through the LET'S MIMIC framework. The ultimate goal is to enhance student engagement and learning outcomes while fostering innovation and sustainability in design.

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2. The need for climate action and green skills development

Climate change, a pressing issue of the 21st century, demands immediate and sustained action to mitigate its impacts. The escalating frequency and severity of natural disasters, rising global temperatures, and deteriorating ecosystems underscore the urgency of addressing climate change (IPCC, 2021). There is a critical need for climate action and the development of green skills as integral components in combating climate change and fostering sustainable development.

The scientific consensus on climate change is unequivocal: it's us, human activities, particularly the burning of fossil fuels and deforestation, that are driving unprecedented changes in the Earth's climate. These changes pose profound risks to natural and human systems, including:

- **Environmental degradation**: Loss of biodiversity, ocean acidification, and deforestation are directly linked to climate change, resulting in disrupted ecosystems and diminished natural resources.
- **Economic impacts**: Climate change affects economic stability through increased costs associated with disaster response, health care, and infrastructure damage, potentially reducing global GDP significantly.
- **Social and health risks**: Vulnerable populations, particularly in developing regions, face heightened risks of food and water scarcity, health issues, and displacement due to climate-induced disasters.

Urgent climate action is required to limit global warming to well below 2°C above pre-industrial levels, as outlined in the Paris Agreement (UNFCCC, 2015). Achieving this goal demands a multifaceted approach involving policy changes, technological innovation, and widespread societal engagement. The transition to a green economy is imperative to mitigate the adverse effects of climate change and promote sustainable development. This transition involves significant changes in energy production,

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industrial processes, waste management, and lifestyle choices. Green skills are necessary for several reasons:

- **Economic transformation**: As industries move towards greener practices, there is a growing demand for a workforce skilled in sustainable technologies and processes.
- **Environmental protection**: Green skills enable individuals and organisations to reduce their environmental footprint, conserve resources, and protect ecosystems.
- **Social equity**: Equipping all societal groups with green skills ensures inclusive participation in the green economy, promoting social equity and reducing disparities.

Building green skills constitutes a strategic and needed response to climate change (UNESCO, 2017). Green skills encompass the knowledge, abilities, values, and attitudes needed to live in, develop, and support a sustainable and resource-efficient society (ILO, 2019). The transition to a green economy requires a workforce equipped with these skills to implement and maintain sustainable practices across various sectors (OECD, 2020).

Green skills can contribute to all aspects of social and economic sustainable growth and quality of life by introducing environmentally friendly solutions in diverse sectors, such as:

- **Renewable energy**: Biomimicry can inspire more efficient renewable energy technologies. For example, wind turbine blades designed based on the shape of whale flippers or the structure of bird wings can capture wind more effectively, increasing energy output.
- **Water management**: Nature-inspired water collection and purification solutions can enhance water security. Techniques such as mimicking the water-collection methods of desert beetles or the filtration systems of mangrove trees can lead to more sustainable water management practices.

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- **Sustainable architecture**: Biomimicry can inform the design of energy-efficient buildings. Structures that mimic termite mounds' natural ventilation systems or the cooling mechanisms of cacti can reduce the need for artificial heating and cooling, lowering energy consumption.
- **Agriculture and food security**: Adopting agricultural practices inspired by natural ecosystems, such as polycultures that mimic the diversity and resilience of natural plant communities, can improve soil health, increase yields, and reduce reliance on chemical inputs.
- **Waste management**: Biomimicry offers solutions for waste reduction and recycling. For instance, circular economy models inspired by closed-loop systems in ecosystems can minimise waste and enhance resource efficiency.

Education systems and training programs play a pivotal role in developing green skills. Integrating sustainability into curricula at all levels, from primary education to higher education and vocational training, ensures that future generations are equipped to address climate challenges. Additionally, continuous professional development and reskilling opportunities for the current workforce are necessary to adapt to the evolving demands of a green economy.

Given the far-reaching and potentially catastrophic impacts of climate change, the urgency of climate action cannot be overstated. Building green skills is a strategic imperative that supports the transition to a sustainable, low-carbon future. By investing in education and training, societies can empower individuals to contribute to climate solutions, drive economic growth through green jobs, and ensure a resilient and equitable world for future generations. Concerted local, national, and global efforts are essential to achieve these objectives and secure a sustainable future for all.

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3. Overview of Project-Based Learning

3.1 Definition of Project-Based Learning

Project-Based Learning (PBL) is an instructional methodology that encourages students to learn and apply knowledge and skills through an engaging experience centred around complex, real-world, and meaningful projects (Thomas, 2000). Unlike traditional instructional methods that rely on rote memorisation and passive learning, PBL places students at the centre of the learning process, allowing them to explore and solve meaningful problems and emphasising active learning, critical thinking, collaboration, and the application of knowledge to real-world situations. PBL fosters deep learning by allowing students to explore and respond to complex questions, problems, or challenges.

Key characteristics of PBL include (Larmer & Mergendoller, 2010):

- **Student-centered learning**: Students take ownership of their learning, working independently or in groups to explore and address the project's central question or challenge.
- **Interdisciplinary approach**: PBL projects often integrate multiple subject areas, helping students make connections between different fields of knowledge.
- **In-depth inquiry and research:** Students engage in inquiry-based learning, researching and gathering information to inform their projects.
- **Collaboration**: Students collaborate with peers, educators, and sometimes external experts, fostering teamwork and communication skills.
- **Authentic assessment**: Assessment in PBL is performance-based, focusing on the process and final product rather than traditional tests and exams. Authentic assessment evaluates student skills in a manner that simulates their actual use in the real world. It validates that students can use the skills and transfer them from the academic environment to everyday life.

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- **Student voice and choice**: Students have a say in the direction of their project, including decisions about the process and outcome.
- **Reflection**: Continuous reflection on learning experiences, processes, and outcomes is integral to PBL.
- **Critique and revision**: Students give, receive and use feedback to improve their work and understanding.
- **Benefitting communities**: Project results are often shared with an audience beyond the classroom.

3.2 Learning advantages of Project-Based Learning

PBL offers numerous advantages that enhance educational outcomes and prepare students for future challenges (Blumenfeld et al, 1991):

- **Deeper learning**: By engaging with real-world problems, students develop a deeper understanding of the subject matter and its applications.
- **Critical thinking and problem-solving**: PBL promotes higher-order thinking skills as students analyse, synthesise and evaluate information.
- **Collaboration and communication**: Working in teams, students improve their ability to collaborate, communicate effectively, and manage conflicts.
- **Engagement and motivation**: The authenticity and relevance of projects increase student engagement and intrinsic motivation.
- **Soft skill development**: PBL helps students acquire essential skills such as research, project management, and self-directed learning.
- **Preparation for the future**: PBL prepares students for the complexities of the modern world by developing adaptability, creativity, and lifelong learning skills.

3.3 Project-Based Learning steps and implementation

The four critical steps of PBL are (Bell, 2010):

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1. **Project launch:** Introducing the project, setting goals, and initiating brainstorming sessions.
2. **Ideation and inquiry:** Engaging in research and exploration to generate ideas and formulate hypotheses.
3. **Develop, critique, and revise:** Creating prototypes, receiving feedback, and making iterative improvements.
4. **Present and defend solutions:** Presenting the final solution and defending the design choices through formal presentations and reflective discussions.

3.4 Challenges and considerations

Implementing PBL in educational settings requires thoughtful planning and support. Regarding activity design, projects must be carefully structured to align with academic standards and learning objectives while allowing student agency. Teachers' roles evolve as facilitators and guides, providing resources, scaffolding, and support as needed. Assessment in PBL is multifaceted, including formative assessments, peer evaluations, and summative assessments of the final product and process. Educators need ongoing professional development to design, manage, and assess PBL experiences effectively. Implementing PBL can require significant resources, including time, materials, and access to expertise (Krajcik & Blumenfeld, 2006).

4. Biomimicry and its importance in design

4.1 Biomimicry definition and main aspects

Biomimicry, derived from the Greek words "bios" (life) and "mimesis" (imitation), is an interdisciplinary approach that seeks to solve human challenges by emulating nature's time-tested patterns and strategies (Benyus, 1997). The concept involves studying biological entities and processes to inspire innovative solutions in various fields such as engineering, design, architecture, and technology. The goal is to create more efficient,

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sustainable, and resilient products and systems by harnessing the genius of nature. Biomimicry involves studying and imitating nature's forms, processes, and ecosystems to get inspiration for addressing modern challenges. This interdisciplinary approach bridges biology, engineering, design, and innovation, aiming to create sustainable solutions by learning from the efficiencies and resilience inherent in natural systems. It leverages the millions of years of evolutionary refinement inherent in natural systems, resulting in inherently sustainable and efficient solutions (Vincent et al, 2006).

The main aspects of biomimicry are (Bhushan, 2009):

- **Emulation of natural forms**: Designing structures and materials that mimic the shapes and forms found in nature, such as the streamlined body of a fish for hydrodynamic vehicles or the hexagonal structure of a honeycomb for lightweight, strong materials.
- **Emulation of natural processes**: Adopting processes observed in nature, such as photosynthesis for energy production or the self-cleaning properties of lotus leaves for surfaces that repel dirt and water.
- **Emulation of natural ecosystems**: Creating systems that function like natural ecosystems, where waste from one process becomes input for another, aiming for zero waste and closed-loop systems.

4.2 Biomimicry examples

Biomimicry is evident in solutions used widely in everyday life and within businesses. Examples of products or solutions designed through biomimicry include:

- **Velcro®**: Inspired by the way burrs stick to animal fur, Velcro uses tiny hooks and loops to create a robust, reusable fastening system.
- **Bullet train design**: The shape of the Shinkansen bullet train's nose was inspired by the beak of a kingfisher bird, reducing noise and improving energy efficiency.

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- **Self-healing materials**: Inspired by biological systems that repair themselves, researchers are developing materials that can automatically heal cracks and damages.
- **Lotus effect**: Inspired by lotus leaves' ability to repel water and self-clean, self-cleaning surfaces for windows, paints, and textiles repel water and dirt.
- **Gecko tape**: Inspired by gecko feet, which use microscopic hair structures to adhere to surfaces, adhesive tapes and climbing robots that can stick to walls without glue.
- **Whale fin wind turbines**: Inspired by humpback whale fins with tubercles (bumps), wind turbine blades with a serrated edge increase efficiency and stability by reducing drag.
- **Termite mounds**: The natural ventilation systems of termite mounds inspired passive cooling and ventilation designs in buildings, such as the Eastgate Centre in Harare, Zimbabwe.
- **Butterfly wings**: The iridescent scales of butterfly wings inspired colour-changing materials for textiles, sensors and displays without dyes or pigments.
- **Shark skin**: The microscopic ridges on shark skin that reduce drag and prevent bacteria from attaching inspired anti-fouling coatings for ships, antibacterial surfaces for medical devices and streamlined swimsuits.
- **Beetle condensation**: The Namib Desert beetle, which collects water from the fog on its textured shell, inspired water harvesting systems in arid regions that utilise surfaces that capture and channel moisture from the air.

Biomimicry offers a way to innovate sustainably by learning from and mimicking the strategies that have enabled life to thrive on Earth for billions of years. Integrating biomimicry into the design curriculum through PBL equips students with cutting-edge knowledge and skills and fosters an ethical and sustainable mindset. This holistic approach to education prepares students to become innovative and responsible designers capable of addressing the pressing challenges of the 21st century.

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4.3 Biomimicry steps and implementation

The biomimicry design process involves several key steps to ensure that the principles and strategies found in nature are effectively applied to human challenges. Following is a detailed overview of the typical steps in a biomimicry design process:

- **Define**: Clearly define the impact you wish your design to have on the world and the criteria and constraints that will determine its success. The purpose of this phase is not to determine the content of your design or creation but rather to comprehend its purpose, audience, and context. It may be alluring to expedite this process; however, this can result in premature conclusions.
- **Biologise**: Examine the critical functions and context that your design solution must address. Rephrase them in biological terms to enable you to "consult nature." This step aims to formulate one or more "How does nature..." inquiries that can serve as a foundation for your research as you seek biological models in the subsequent step (Discover) of the Design Spiral.
- **Discover**: Seek natural models (e.g., organisms and ecosystems) that address your design solution's functions and context. Determine the strategies that facilitate their survival and prosperity. This phase emphasises the acquisition of information and conducting investigation.
- **Abstract**: Conduct a thorough examination of the critical components or mechanisms that contribute to the effectiveness of biological strategies. Ensure you understand the features accurately by utilising sketches and writing them down in clear language. Developing a design strategy aims to facilitate the conversion of biological insights into design solutions.
- **Emulate**: Search for patterns and relationships among the strategies you have identified and concentrate on the primary lessons that should guide your solution. Formulate design concepts informed by these strategies. Emulation is the fundamental principle of biomimicry; it involves applying insights gained from living organisms to the problems humans seek to resolve. Emulation is an

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exploratory process that aims to capture a "recipe" or "blueprint" in nature's example that can be replicated in our designs rather than rote copying of nature's strategies.

- **Evaluate**: Evaluate the design concepts concerning their alignment with the design challenge's criteria and constraints and compatibility with Earth's systems. Evaluate the feasibility of the technical and business model. Revise and revisit previous steps as necessary to generate a viable solution.

Each step in the biomimicry design process emphasises learning from nature's wisdom, ensuring that solutions are effective, sustainable, and harmonious with the natural world.

4.4 Biomimicry advantages in design

Biomimicry offers advantages in design, which can be summarised as follows (Kennedy, 2016):

- **Innovation:** Biomimicry inspires innovative design solutions that often outperform conventional approaches. By learning from nature, designers can develop new materials, structures, and processes that are both effective and sustainable.
- **Sustainability:** Natural systems are inherently sustainable, operating in closed loops with minimal waste. Biomimicry promotes the development of sustainable technologies and practices that reduce environmental impact.
- **Resilience:** Nature has evolved to thrive under various conditions, leading to resilient and adaptable designs. Biomimetic designs can better withstand changing environmental and societal conditions.
- **Aesthetics:** Natural designs are often inherently beautiful, appealing to human aesthetics and enhancing the user experience.
- **Efficiency**: Nature’s designs are optimised for energy and resource efficiency, leading to solutions that reduce waste and minimise resource consumption.

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4.5 Challenges and considerations

While biomimicry holds excellent promise, challenges and considerations must be addressed. This includes the complexity of nature, as understanding and replicating the complexity of natural systems can be difficult, requiring extensive research and interdisciplinary collaboration. It further involves scalability, translating biomimetic principles into scalable solutions that can be widely adopted remains challenging. Finally, a challenge for applying biomimicry is intellectual property, with innovations inspired by nature that may raise questions about intellectual property rights and the sharing of biomimetic knowledge (Bar-Cohen, 2006).

5. The LET'S MIMIC framework for integrating Biomimicry Design into Project-Based Learning

The PBL framework for the biomimicry process design project is structured around the key principles of PBL, ensuring a systematic and effective learning process. As stated above, the key steps of PBL are project launch, ideation and inquiry, developing, critiquing, revising and presenting and defending solutions.

The LET'S MIMIC framework has been designed using PBL as the basis of the structure of learning, integrating biomimicry. The result incorporates the best of both methodologies, empowering students to innovate by being inspired by nature. Below is the Biomimicry Design Process and how it aligns with Project-Based Learning (PBL)

1. Identify the challenge (PBL) / Define the problem (Biomimicry)

- **PBL**: Identify a real-world problem to explore and solve.
- **Biomimicry**: Define the design challenge by understanding the specific issue that nature might have already solved.
- **Integration**: Frame projects around natural challenges or sustainability-focused problems, like renewable energy or waste reduction.

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2. Research and inquiry (PBL) / Biologize the challenge (Biomimicry)

- **PBL**: Research the problem and inquire into possible solutions.
- **Biomimicry**: Break the challenge into its fundamental needs and processes, viewing the problem through nature's strategies.
- **Integration**: Analyse the problem by asking, "How does nature solve this challenge?" For example, they might research how animals insulate their homes and apply those principles to building design.

3. Ideation and solution design (PBL) / Discover natural models (Biomimicry)

- **PBL step**: Brainstorm and generate ideas for potential solutions.
- **Biomimicry step**: Look for organisms, ecosystems, or natural processes that solve similar challenges.
- **Integration**: Explore examples of nature's solutions, such as the structure of a honeycomb for efficient space use or the water repellence of a lotus leaf for self-cleaning materials.

4. Abstract (Biomimicry)

- **Biomimicry**: Abstract the underlying principles or strategies from natural models (e.g., efficiency, adaptability, resilience).
- **Integration**: Generalise nature's strategies, such as the lightweight strength of a bird's bones, to apply these principles to their project design. This step encourages students to think more broadly about how biological principles can be adapted to human challenges.

5. Prototype development (PBL) / Emulate (Biomimicry)

- **PBL**: Create prototypes of suggested solutions and start testing.
- **Biomimicry**: Emulate abstracted principles from nature to build a sustainable design that solves the problem.

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- **Integration**: Build prototypes that mimic nature's strategies, such as creating ventilation systems inspired by termite mounds or designing surfaces inspired by shark skin for antifouling purposes.

6. Testing and feedback (PBL) / Evaluate and refine (Biomimicry)

- **PBL**: Test prototypes, gather feedback and make necessary refinements.
- **Biomimicry**: Evaluate the design's effectiveness and sustainability, refining the solution based on feedback and ensuring it aligns with nature's principles.
- **Integration**: Test how effectively suggested nature-inspired solutions work and iterate based on efficiency, environmental impact, and functionality.

7. Present the solution (PBL) / Contextualize and apply (Biomimicry)

- **PBL**: Present solutions to the class or community.
- **Biomimicry**: Contextualize the biomimetic solution by applying it to real-world situations while keeping it aligned with natural and sustainable principles.
- **Integration**: Explain how their final design solves the problem and follows nature's example, contributing to sustainable solutions.

5.1 The LET'S MIMIC Matrix

The following matrix outlines the alignment between the **Project-Based Learning (PBL)** steps and the **Biomimicry Design Process into the LET'S MIMIC Framework**, highlighting how each stage in PBL can incorporate biomimicry principles. This integration encourages students to analyse and solve real-world problems by looking to nature for inspiration, ultimately fostering creative, sustainable, and efficient solutions. By combining these processes, students engage in hands-on learning while applying natural strategies to human-centred design challenges.

PBL step	Biomimicry Design Process step	Integration example

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Identify the challenge	Define the Problem	Frame the challenge as a sustainability issue nature can help solve
Research and inquiry	Biologise the challenge	Analyse the problem through a biological lens
Ideation and solution design	Discover natural models	Use natural examples like plant growth patterns for solutions
Ideation and solution design	Abstract	Generalise natural principles (e.g., strength, efficiency) for broader application
Prototype development	Emulate	Build prototypes based on abstracted natural principles (e.g., designing a structure based on a spider's web)
Testing and feedback	Evaluate and refine	Test solutions with sustainability and ecological fit in min
Present the solution	Contextualise and apply	Present how the solution integrates biomimicry and sustainability

Table 1. Integration of Project-Based Learning and Biomimicry Design in LET'S MIMIC methodological framework.

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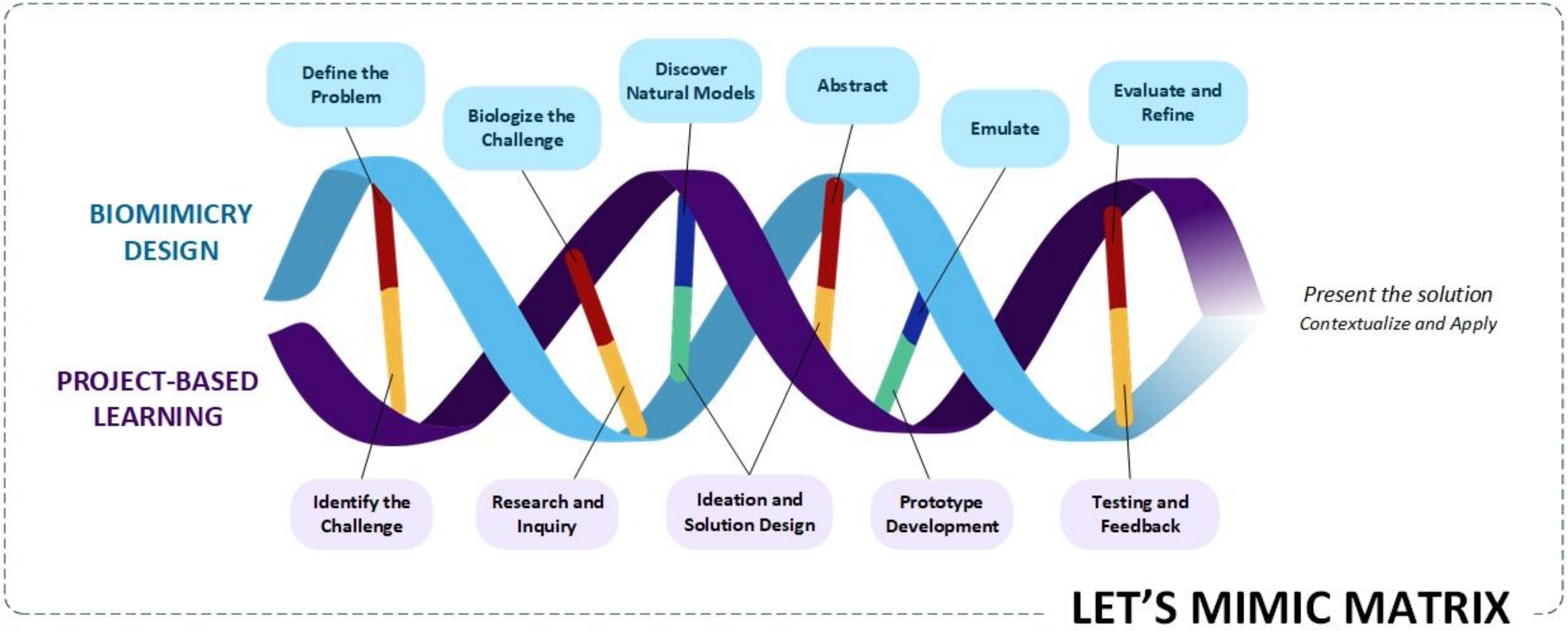

Figure 1. LET'S MIMIC methodological framework that integrates Biomimicry Design Process with Project-Based Learning.

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5.2 Examples illustrating how each step of the biomimicry process can be integrated into PBL

Integrating the **Biomimicry Design Process** with **Project-Based Learning (PBL)** enhances students' ability to solve real-world problems by looking to nature for sustainable solutions. Each step of PBL aligns with a corresponding stage of the biomimicry process, allowing students to approach challenges with creativity and systems thinking. By studying how nature has evolved to address similar challenges, students can design innovative solutions that are both efficient and ecologically sound.

The following examples illustrate how each step of the biomimicry process can be integrated into PBL, using a challenge related to **water conservation** as the central theme. These examples highlight the natural models and principles students can draw from, encouraging them to emulate nature's time-tested strategies in their project designs.

1. Identifying the challenge (PBL) / Define the problem (Biomimicry)

- **Example**: Students identified the challenge of water scarcity in urban areas due to inefficient water usage and waste.
- **Biomimicry Focus**: Define the problem by asking how nature conserves and uses water efficiently. Nature often employs efficient water storage, minimal loss, and reuse mechanisms.
- **Integration**: Frame the project around designing a water-efficient system inspired by nature, like how plants conserve water in dry environments.

2. Research and inquiry (PBL) / Biologize the challenge (Biomimicry)

- **Example**: Research the problem of urban water scarcity and examine existing solutions, such as water filtration and conservation technologies.

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- **Biomimicry focus**: Break the problem down into core needs, such as storing, filtering, and minimising water loss. Investigate how natural systems perform similar functions.
- **Integration**: Investigate biological solutions to water conservation, such as how desert plants store water or how certain animals survive in arid conditions.

3. Ideation and solution design (PBL) / Discover natural models (Biomimicry)

- **Example**: Begin brainstorming potential solutions and discover natural models. Look at examples from nature, such as how cacti store water or how beavers create natural filtration systems in their dams.
- **Biomimicry focus**: Search for specific organisms or ecosystems that have evolved solutions for water conservation.
- **Integration**: Identify a natural model, for example, how certain beetles in the Namib Desert collect water from fog on their wings, and brainstorm how this can be applied to human technology.

4. Abstract (Biomimicry)

- **Example**: Extract the key principle from the beetle's fog-harvesting technique: **surface texture and shape** are used to capture water.
- **Biomimicry focus**: Abstract this strategy into a design principle: use specialized surfaces to collect water from the air.
- **Integration**: Generalize the principle of using structure and texture for water collection and think about how this can be applied to the design of urban water systems, such as rooftops that capture moisture from the air.

5. Prototype development (PBL) / Emulate (Biomimicry)

- **Example**: Develop a prototype of a water collection system for urban homes. Their design emulates the beetle's strategy by creating a surface that captures water from fog or dew.

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- **Biomimicry Focus**: Design the prototype by emulating the form and function of natural models, using the abstracted principles to inform the design.
- **Integration**: Create a rooftop system with a textured surface similar to the beetle's wings, optimized to collect and channel water into a storage tank.

6. Testing and feedback (PBL) / Evaluate and refine (Biomimicry)

- **Example**: Test the suggested water collection system under different environmental conditions, measuring its effectiveness at collecting water from moisture in the air.
- **Biomimicry focus**: Evaluate the design's performance and ensure it aligns with sustainability and natural efficiency principles.
- **Integration**: Refine their design based on testing feedback, adjusting the surface texture or size to improve water collection. They ensure the design is energy-efficient, just like nature's processes.

7. Present the solution (PBL) / Contextualize and apply (Biomimicry)

- **Example**: Present the final design of the suggested water collection system to the class or community, explaining how their design is inspired by nature and how it can help address urban water scarcity.
- **Biomimicry Focus**: Contextualize the design by explaining how it fits into real-world applications and contributes to solving sustainability challenges.
- **Integration**: Highlight how the suggested water collection system mimics natural processes and can be implemented in urban areas to reduce reliance on traditional water sources and make cities more resilient to drought.

These examples illustrate how the **Biomimicry Design Process** can be applied to each step of **Project-Based Learning**, from identifying a challenge to presenting a final solution, all while fostering creative problem-solving inspired by nature.

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6. Learning outcomes

The proposed learning framework that integrates biomimicry in PBL contributes to the development of sustainability **knowledge**, **skills** and **competencies** in demand by industry and society:

- **Knowledge:** The understanding and comprehension of key concepts, principles and theories related to sustainability skills in VET, informed by desk research and questionnaire findings.
- **Skills:** The practical abilities and competencies developed through hands-on learning experiences and activities aimed at applying sustainability principles effectively within VET contexts.
- **Competences:** The broader capabilities and capacities acquired, including critical thinking, problem-solving, and decision-making skills, necessary for integrating sustainability into vocational education curricula.

In addition, it helps develop soft green **skills**, which are appreciated in the job market. This includes:

- **Curiosity and inspiration**: Biomimicry involves solving real-world problems by mimicking nature's designs and processes, making learning more relevant and engaging for students. The natural world provides fascinating examples that can spark curiosity and inspire students to explore and learn.
- **Critical thinking, complex problem-solving, and systems thinking skills**: Biomimicry challenges students to solve complex, authentic problems, promoting critical thinking and innovative problem-solving skills. Understanding how natural systems work and applying these principles requires and develops systems thinking abilities.
- **Contextual learning**: Biomimicry helps develop integrated knowledge by inherently integrating biology, engineering, design, and environmental science, providing a rich, interdisciplinary learning experience. Students can establish the

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connections between different subjects and understand how they apply in real-world contexts.

- **Environmental consciousness and ethical thinking**: Learning from nature fosters an appreciation for the environment and the importance of sustainability. Students learn to consider ethical implications and the long-term impact of their designs and solutions.
- **Creativity and innovation**: Biomimicry encourages students to think creatively, using nature as a model, mentor, and measure for innovative solutions.
- **Design thinking**: Integrating design thinking principles with biomimicry promotes creativity and iterative development processes.
- **Collaboration**: PBL often involves collaborative projects, helping students develop teamwork and communication skills.
- **Communication**: Students frequently present their findings and solutions, enhancing their ability to communicate complex ideas effectively.
- **Hands-on and experiential learning to learn**: PBL and biomimicry involve hands-on activities, experiments, and real-world applications, which can enhance understanding and retention. Students gain practical skills in research, prototyping, testing, and iteration.
- **Resilience and adaptability**: Studying how organisms adapt to their environments teaches students resilience and adaptability, essential skills for the modern world. The iterative nature of biomimicry projects helps students learn to cope with failure and persist in facing challenges.

7. Assessment strategies

Assessment in the LET'S MIMIC Framework context builds upon the PBL methods and self-regulated learning approaches. It involves formative assessment to monitor student progress and performance assessment to evaluate outcomes. These strategies are crucial for ensuring that learning objectives are met effectively.

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8.1 Formative assessment

The formative assessment, driven by the PBL framework, focuses on providing ongoing student feedback. It allows mentors to monitor student understanding, adjust teaching strategies, and guide students towards achieving the desired learning outcomes. Formative assessment methods may include:

- **Peer assessment**: Opportunities for students to evaluate each other's work, promoting collaboration and critical thinking as they discuss and reflect on their peers' contributions.
- **Self-reflection**: Reflection activities where students assess their learning and progress, identifying areas where they need further development. This is connected to the self-regulation learning approach supported through the LET'S MIMIC methodology, which aims to improve students' abilities to manage their learning processes by learning how to plan, monitor, and evaluate their learning strategies and progress. At a more granular level, it assesses students' abilities to understand and explore a task, set goals and plan activities, achieve objectives, etc.

Formative assessment supports the iterative nature of PBL by encouraging continuous improvement and fostering a supportive learning environment where students can experiment and learn from mistakes.

Here are some practical formative assessment methods paired with tools that can be used to gauge students' understanding and progress during learning. These methods help provide timely feedback to both educators and students for ongoing improvement.

1. Exit Tickets

- **Method**: At the end of a lesson, ask students to submit a quick response to a specific question or prompt.
- **Tools**:

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- **Google® Forms** or **Microsoft® Forms** for digital exit tickets.
- **Padlet®** for shared class exit tickets with comments or ideas.

Example: Ask, "What's one thing you learned today and one question you still have?" Students can quickly type or submit responses, providing insight into their understanding.

2. Quizzes and Polls

- **Method**: Use quick quizzes or polls during or after lessons to check for understanding of key concepts.
- **Tools**:
    - **Kahoot®** for fun, competitive quizzes.
    - **Mentimeter®** for live polling and interactive quizzes.
    - **Socrative®** for creating real-time quizzes with immediate feedback.

Example: After a lesson on ecosystems, you could use Kahoot to test students' knowledge of ecological relationships in a game format.

3. Think-Pair-Share

- **Method**: Students think about a question individually, discuss it with a partner, and finally share their responses with the class.
- **Tools**:
    - **Zoom® breakout rooms** or **Google® Meet breakout rooms** for virtual pair discussions.
    - **Jamboard®** or **Padlet®** for sharing collective class responses.

Example: After introducing a new math concept, ask students to think about how they would solve a problem, pair up to discuss strategies, and then share with the whole class using Jamboard®.

4. Concept Mapping

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- **Method**: Have students create visual maps to show their understanding of connections between ideas.
- **Tools**:
    - **MindMeister®** or **Coggle®** for creating digital concept maps.
    - **Lucidchart®** for more advanced mind mapping and diagramming.

Example: Students can create a concept map to visualize the relationship between water cycles and ecosystems, helping the teacher assess how well they understand interconnections.

5. Peer Review

- **Method**: Students provide feedback to their peers on assignments or projects, helping them reflect on their work as well.
- **Tools**:
    - **Google® Docs** or **Microsoft® Word** for shared commenting features.
    - **Peergrade®** for structured peer feedback assignments.

Example: After writing an essay, students can exchange papers and provide feedback using Google Docs' comment feature. Teachers can also monitor the comments for both content and quality.

6. One-Minute Paper

- **Method**: Ask students to write down in one minute the most important thing they learned or any lingering questions.
- **Tools**:
    - **Padlet®** or **Google® Keep** for quick, digital responses.
    - **Flipgrid** for short video responses.

Example: After a lesson on climate change, students take one minute to write down their key takeaways and any uncertainties, helping the teacher know what to review.

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7. Self-Assessment Rubrics

- **Method**: Allow students to reflect on their learning progress using a rubric.
- **Tools**:
  - **Google® Sheets** for custom rubrics and tracking.
  - **Seesaw®** for interactive self-assessment activities, where students can
  - annotate their work and reflect.

Example: Provide students with a rubric for a group project and have them rate their contributions and areas for improvement. Then, follow up with a reflection activity on Seesaw®.

8. Digital Journals or Blogs

- **Method**: Encourage students to keep a journal or blog to reflect on their learning, encouraging metacognition and ongoing assessment.
- **Tools**:
  - **Google® Docs** or **Microsoft® OneNote** for digital journals.
  - **Edublogs®** for creating student blogs for public or private reflections.

Example: After each lesson, students write a brief reflection on what they learned and any challenges they faced. This helps the teacher track their thought process over time.

9. Interactive Whiteboards for Real-Time Feedback

- **Method**: Use interactive whiteboards for real-time brainstorming or collaboration. Teachers can assess understanding as students contribute.
- **Tools**:
  - **Miro®** or **Jamboard®** for real-time collaboration and visualization of student ideas.
  - **Nearpod®** for interactive presentations where students can respond live.

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Example: During a lesson on fractions, students can solve problems collaboratively on a shared Jamboard®, allowing the teacher to assess problem-solving strategies.

10. Video and Audio Reflections

- **Method**: Have students record short videos or voice notes to explain their understanding of a topic or respond to prompts.
- **Tools**:
  - **Flipgrid®** for student video reflections.
  - **Vocaroo®** or **Audacity®** for audio reflections.

Example: After a science experiment, students record a Flipgrid video explaining their findings and what they would do differently next time. This allows for reflection and self-assessment.

8.2 Performance assessment

Performance assessment in the PBL framework focuses on evaluating the final products or solutions developed by students and their ability to communicate and defend their work effectively. It aims to measure how students have achieved the intended learning outcomes. Methods of performance assessment include:

- **Final presentations**: Students present their biomimicry-inspired design solutions to a panel of instructors, peers, and possibly external experts. They demonstrate their understanding of biomimicry principles, the effectiveness of their design, and its sustainability implications.
- **Portfolio reviews**: Evaluation of a portfolio that documents the entire project process, including research, prototypes, iterations, and reflections. Portfolios showcase the evolution of students' ideas and their application of biomimicry concepts.

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- **Defense sessions**: Structured sessions in which students defend their design choices, explain how biomimicry principles informed their decisions, and address questions from the assessment panel.
- **Performance rubrics**: Criteria-based assessment tools that guide evaluators in assessing the quality of students' work and progress, providing specific and actionable feedback. From the self-regulated learning perspective, this includes specifically assessing a student's willingness and drive to engage in self-assumed learning paths and activities, set goals, plan, and complete tasks on their own.

Therefore, to foster a deeper understanding and application of biomimicry principles in design, the performance assessment in the LET'S MIMIC context builds not only on PLB strategies that measure the student's mastery of content knowledge and skills and evaluate their ability to apply learning in an authentic context but also on self-regulated learning assessment methods that consolidate the students' self-awareness, self-efficacy, as well as their abilities to maintain motivation, to manage time, be resilient, etc.

8. Summary of the LET'S MIMIC framework

The LET'S MIMIC framework, developed for integrating PBL with biomimicry process design, represents a structured approach to fostering sustainability skills among vocational education and training (VET) learners. It presents the matrix, which summarises the alignment between the Project-Based Learning (PBL) steps and the Biomimicry Design Process.

11.1 Expected impact

The implementation of this framework is expected to yield several significant impacts:

- **Enhanced learning outcomes**: Students will develop a deeper understanding of biomimicry principles and their application in design, along with essential skills in research, critical thinking, and collaboration.

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- **Promotion of sustainability**: By integrating biomimicry into the curriculum, students will contribute to sustainable practices and innovations that address real-world challenges.
- **Skill development**: Through hands-on projects and assessment strategies, students will acquire practical skills directly applicable to future careers and educational pursuits.
- **Innovation and creativity**: Encouraging students to explore biomimetic solutions fosters creativity and innovation, preparing them to tackle complex problems in diverse fields.

11.2 Future directions

Looking forward, there are several avenues for further development and enhancement of this framework:

- **Scaling and adaptation**: Expanding the framework to other educational contexts and disciplines to promote broader adoption of biomimicry and PBL methodologies.
- **Integration of technology**: Leveraging emerging technologies such as artificial intelligence and digital simulation to enhance biomimetic design capabilities and student learning experiences.
- **Continuous improvement**: Iteratively refining the framework based on feedback from educators, students, and industry partners to ensure relevance and effectiveness.
- **Research and evaluation**: Conducting longitudinal studies to assess the long-term impact of the framework on student learning outcomes, career readiness, and sustainability practices.

The framework aims to remain at the forefront of educational innovation by continuously evolving and adapting. Through biomimetic design and sustainable

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practices, it equips learners with the knowledge, skills, and competencies needed to address global challenges.

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