

# Improvement of Creativity via the Six-Step Bio-Inspiration Strategy

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## Abstract

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Bionics is a relatively new interdisciplinary science, which synthesizes the knowledge of biology and other sciences. Industrial designers, architects and engineers find the application of principles and methods of bionics efficient for deriving inspiration and improving their creative thinking. Designers explore natural systems by adopting one of the two main bionic strategies: solution-driven or problem-driven approach. The first one deals with the abstraction of the principle in biological systems as an inspiration for application in the product design process. The second one searches for a solution in natural systems for already recognized design problems. We adopted the Bi-directional bionic design method proposed by Versos and Coelho and started to implement it in our educational process. Many student projects have been made and important experience achieved. With this research, we wanted to emphasize the possibilities and advantages of the bionic strategy and to offer our contribution for the phase of inspiration for a new product development or an improvement of the existing ones. Our main goal was to apply a solution oriented strategy for efficient exploring of nature in the phase of searching for inspiration. We propose several steps in the process of exploration of natural systems followed by identification of important natural solutions and a structured way of documentation in order to become more noticeable and observable to attract an attention of designers and engineers. The recognized natural solutions could become a trigger for inspiration for various design solutions. The proposed strategy could be applied in the education of design and engineering students for improvement of their creativity.

## 1. Introduction

Biologically inspired design (also known as biomimicry, biomimetics and bionics) views nature as an infinite library of robust, efficient and multifunctional designs, and promotes the use of principles discovered in natural systems as an inspiration for designing technological systems, as well as a standard for evaluating technological designs [1].

According to some researchers bionics is an interdisciplinary field which deals with structures, methods and processes found in biological systems and searches for inspiration in nature to provide solutions for design problems in different fields and various branches, such as architecture, product design, tissue engineering, bioengineering, aeronautics, space science, biomaterials etc. [1]. Bionic design can be considered as a tool that provides form aspects and functional principles in generating concepts and developing products.

In his definition, Neuman represents the relationship between bionics with bio systems and their

environment, while Nachtigall emphasizes the importance of searching for inspiration and learning from nature, but not its full replication for human needs. Other researchers view bionics as a tool - not more but not less. Bionics is not a cure and not a copy of nature. Bionics is no universal tool for solving problems, but may in the best way be an excellent assisting tool [2].

Many researchers worked on developing strategies and methods for practising biologically inspired design process. Bionic design methodologies are guidelines and essential tools in the design process, they allow the designers to rely on them when they face a challenge, but this does not always itself guarantee the success of the designed product.

Helms, Vattam and Goel [2] propose an organizing framework for practising of biologically inspired design, which could be applied to both problem-driven and solution-driven process. Carlos A. M. Versos and Denis A. Coelho propose a Bi-directional bionic design method [3, 4] where two possible starting guidelines were considered: guidance in the direction from the bionic solution to the design

problem and guidance in the direction of the design problem to the bionic solution. The method proposes a series of steps in the design process which could be practised in one of the two alternative orientations considered for the bionic design process. The common steps in both directions of analysis consist of the same activities, contain the same description and are applicable for the two orientations. Versos and Coehlo have established five general goals of the process of bio-inspiration: communication effectiveness, form optimisation (reduction of material or size, stability, reduced pressure, compression, etc.), multiple requirements satisfaction - system to perform various tasks or to fulfill several functions, organisation effectiveness and paradigm innovation for improved functional performance.

## 2. Improvement of Creativity

One of the main steps of the design process is an inspiration. According to English Collins Dictionary "inspiration is stimulation or arousal of the mind, feelings, etc., to special or unusual activity or creativity". According to Oxford Dictionary "inspiration is the process of being mentally stimulated to do or feel something, especially to do something creative". Inspiration is the act or power of exercising an elevating or stimulating influence upon the intellect or emotions. Inspiration could be a sudden, unexpected idea.

Inspiration is an improvement of the creative thinking. Creative thinking is a way of looking at problems or situations from a fresh perspective that suggests unconventional, untraditional, unusual solutions. It can be stimulated both by an unstructured process, such as brainstorming or by a structured process, such as lateral thinking. Lateral thinking is the ability to use an inspiration and imagination to solve problems by looking at them from unexpected perspectives. Lateral thinking involves discarding the obvious, leaving behind traditional modes of thought, and throwing away preconceptions. Creative thinking is the process we use to develop ideas that are unique, useful and worthy of further elaboration. Creativity is making new connections between existing ideas.

### 2.1 Sources of inspiration

Designers usually search for inspiration for new product design exploring different sources. **Evaluation of existing products** is the starting point of each design process. Sometimes this phase could initiate an idea for a new product that could be developed by implementing some principles perceived in the existing products. Designers are curious to

discover how the competitive products are functioning, what their positive and negative sides are, whether they need any improvement, if there is a need for a completely new solution for the same problem etc.

**History of art, design and architecture** is very often used for inspiration. Design solutions applied in the designs from the ancient times and former styles could provoke and stimulate ideas for implementation in a new and unusual manner. Tradition and culture of different nations is a valuable source of inspiration, as well. Traditional forms, patterns, colours, materials and technologies could be applied in an innovative manner which could provide fresh and interesting designs.

**Exploring the existing materials** is another possible source of inspiration. Application of traditional materials in an untraditional, original, unexpected and unusual manner may initiate original designs. An inventive designer should always recognize the possibilities of new materials and technologies and apply them in the unique and unexpected way. Having in mind the fact that the material science and new technologies have a permanent and amazingly rapid development they offer constant and infinite inspiration.

However, the most affluent, impressive and endless source of inspiration is **nature**. It is a huge basin of phenomenal, original, intelligent solutions that could be recognized in biological systems, natural structures, mechanisms, principles of organisation and optimisation, etc.

### 2.2 Biologically inspired design

All of the objects and occurrences in nature are a possible inspiration for designers and engineers. A single object could be explored from multiple aspects, and all of the results could be the inspiration for numerous different design ideas and solutions.

The search for a solution to the established design problems could be implemented using different strategies and approaches. Some of them could be solved through the application of engineering strategies, others by adopting more artistic approaches. For the designers familiar with the bionic principles and strategies it means to search in the huge basin of natural solutions.

A revolutionary idea for a new product design could be inspired by any principle discovered in the natural systems. Solution-based bionic strategy is a powerful tool for achieving this ambition. Solving a specific recognized design problem could be accomplished through application of problem-oriented bionic strategy as a perfect tool for assisting in the design process.

Exploration of nature enables architects, designers and engineers to discover unusual, original, interesting and smart ideas that could be further

applied in new products development. What is important is the fact that a specific discovered natural principle could be applied as an inspiration for a myriad of design solutions. This fact exemplifies that there is a necessity of structured documentation of various experiences to be available for other product design processes, as well as to be shared with other researchers, designers and engineers.

### 3. Six-Step Bio-Inspiration Strategy

We adopted the Bi-directional bionic design method proposed by Versos and Coelho [3, 4] and started to implement it in our educational process. Many student projects have been made and important experience achieved. With this research, we wanted to emphasize the possibilities and advantages of this method and to give a contribution for the phase of inspiration for a new product development, or an improvement of the existing ones. We established our goal to find the efficient structured strategy of deriving inspiration from nature, as well as the possibility to share the experiences with other designers and engineers.

The solution driven strategy is a powerful tool for the designers in the phase of searching for inspiration during the design process. According to the bi-directional bionic design method [3, 4], the design process with orientation from the bionic solution to the design problem starts with identification and recognition of a specific solution in nature and then searches for a problem which could be solved with the application of the discovered principle. During our practising of the bi-directional bionic design method, we noticed that the solution oriented strategy could be elaborated and improved in order to become more efficient for application in the process of searching for inspiration. The main goal of our research is to offer an efficient strategy for exploring the nature in the phases of solution identification, analysis and reformulation of the solution. We developed an approach consisted of six steps in the process of exploration of the natural systems, objects and occurrences, followed by an identification of important core principles and a structured way of documentation in order to become more noticeable and observable to attract the attention of designers and engineers. Some of the identified principles could become a trigger for inspiration for one or more design solutions.

#### 3.1 Exploration of nature

Nature is an enormous library of excellent examples of creativity. Where to start with searching is the first of the problems.

Experiencing biological inspiration, we noticed

that it is very hard for the designer to focus on a particular inspiring example because of the diversity and affluence of nature. Most of the natural objects possess several interesting principles, and all of them could be inspiring. Some of them are easily perceptible and observable; others have to be explored more deeply. How to focus on a particular problem and how to explain depends on the designer's interests and background.




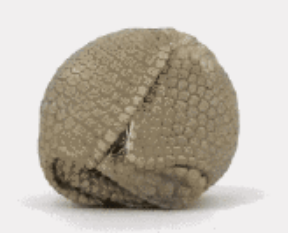




Where to start searching for inspiring natural objects and occurrences? Efficient search for natural creatures, objects and phenomena could be realized in several possible ways:

1. **Observation of the natural environment.** Nature is everywhere around us. Observation and direct interaction are the best ways to recognize an inspiring object and become familiar with its characteristics. Direct interaction with the object includes perception with all senses, observation of behaviour, locomotion principles, organizational principles, etc.
2. **Browsing the existing literature, atlases and encyclopaedias** (printed or on-line versions) for biology, microbiology, mineralogy and other natural science disciplines. They possess all necessary data for gaining an initial interest about a natural object or phenomena as an inspiration, but also for the achievement of deeper understanding and knowledge about it.
3. **Browsing a specialized online library for bionics, biomimicry, etc.** There are several online libraries available for bionic exploring. Ask Nature [5] offered by Biomimicry Institute [6] is a perfect support for the designers in their efforts to recognize natural solutions to different design and engineering problems. Searching for a solution through research articles on biomimetic designs indexed by the function is easy and efficient. What is important is that Ask Nature is permanently loaded with new experiences by designers and other users. Bionicinspiration [7] is an open source project which aim is to collect all known bionic solutions all over the world. Many bionic solutions, offered and proven over millions of years by nature, as answers for many possible design problems, are presented systematically to apply to product design by the support of creativity methods like TRIZ.

#### 3.2 Attraction of attention

The first experience and impression about the natural object are usually achieved by visual sense. Both designers and engineers are triggered to select an object for further exploration according to the first impression (Table 1). Interesting shape, colour, pattern or motion can attract the necessary attention that could awake a curiosity and interest for the next steps of the process of bio-inspiration: identification and exploration of one or more important principles.

**Table 1: Selection of natural objects for further exploration according to the first impression**

Natural object / phenomena	Natural object / phenomena
 	 
 	 

The fact who is the explorer is very important in the phase of the attraction of attention. Explorers from different areas and backgrounds have different interests, and they intuitively explore diverse natural objects and diverse objects' features.

**Product designers are usually attracted of the objects with remarkable appearance.** Product designers are occupied with shaping and appearance of products, as well as with the problems connected to the structural issues, effectiveness in the space organization, safety, functionality. The main relevance for this category of explorers are the visual features of the object - shape, material, texture, colour, as well as structure, functionality and multi-functionality, space organisation, effectiveness and optimisation of the shape and the material.

**Engineers are usually attracted of the objects with remarkable behaviour.** Engineers as explorers are more concerned about the principles that could be explained with technical and scientific

knowledge in the fields of physics, mathematics and chemistry. Their fields of exploration are locomotion, energy exchange, systems and mechanisms of different types, the transformation of the shape, as well as the behaviour which is applicable in the field of artificial intelligence.

### 3.3 Identification of the inspiring natural solutions



The next phase is the identification of one or more inspiring biological solutions of the selected natural object, which means recognition of extraordinary principles with outstanding characteristics. This process is performed through discovering multiple facts about the object:

1. appearance, received by sensory perceptions: shape, colour, texture;
2. material: chemical and physical properties, as well as visual and tactile effects ;
3. structure: skeleton, exoskeleton, tissues, skin;
4. locomotion principles, transformation principles;
5. surviving principles: (principles and mechanisms for protection from predators and other environmental influences etc.)
6. energy exchange principles: (digest, energy obtaining, energy utilization, energy spending and optimisation)
7. organisational principles (living, behaviour and interaction in groups, housing habits)

Sometimes perception with the visual sense is enough for the designers as explorers to identify an important principle. Some natural objects posses principles that could be recognized by direct interaction with the object. It means perception with all senses as well as performing of some basic tests. Direct interaction is the most efficient way for comprehensive observation, but it is not always possible. Other objects need to be explored by application of scientific methods or by studying of available scientific information about them.

The phase of solution identification is based on **perception** and **observation** as exploration methods. The outcome is one or more identified exceptional solutions, documented with a collection of photos, videos, sketches and textual explanations, description of the identified natural solutions with ordinary language. In this process, several identified natural solutions discovered on the same natural object could be described (Table 2).





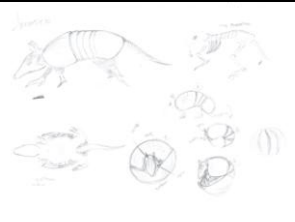



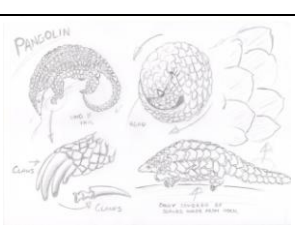
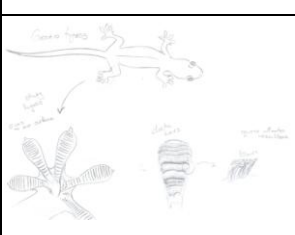
**Table 2: Description of the identified natural solutions with ordinary language**

Natural object / phenomena	Description
	<p><b>Pill millipedes</b></p> <p>Pill millipedes bodies are consisted of eleven to thirteen body segments and are capable of rolling into a ball when disturbed, as a defence against predators.</p>
	<p><b>Ladybug</b></p> <p>Ladybugs have a shell, or hard case, that protects their wings and also protects them from predators.</p> <p>The Elytra is also the part that shows the ladybug's colours and patterns to predators to warn them off.</p>

### 3.4 Exploration of the identified natural solutions

The phase of exploration points towards a complete explanation of the identified natural solutions from all necessary aspects and with all necessary means in order to become clear and recognizable for their possible application in the phase of concept generation. Most of the natural creatures posses several important natural principles, and they could be inspiring for different explorers - designers or engineers.

**Table 3: Examples of documentation of the identified natural solutions exploration**

The outcome of the phase of exploration of a selected natural object is documentation consisted of:

1. geometric exploration drawings;
2. mathematic and geometric descriptions;
3. proportions and other discovered rules;
4. systematically processed empirical data (sizes, measurements, capabilities and limitations, tension, pressure, torque, other forces, etc.);
5. diagrams and sketches for an explanation of functioning or functional decomposition for better understanding of the principle and finding analogy with existing human needs;
6. additional explanations of complex processes, like locomotion or transformation of the shape, with simulations, animations or simple prototypes.

Descriptive geometry methods are perfect instruments for the designers for exploration and explanation of the appearance of the selected natural object. Shapes, patterns, structures, as well as symmetry, rhythm, proportion, could be explored with the application of descriptive geometry methods.

Engineers as explorers need a different approach. Beside the first visual impression, they need experiments and application of scientific methods and instruments in order to provide qualitative and quantitative empirical data which are necessary for explanation of the identified solutions. Form optimisation, reduction of material or size, stability, reduced pressure, compression, etc. are challenges for the engineers, but the results are important for the product designers, as well.


The process of exploration of natural objects and occurrences has to be followed by appropriate documentation. It is very important to extract and recognize the core principles and to make numerous photos, sketches, explanations, text descriptions, etc. Image of the natural object is necessary for visual perception and an initial selection of the inspiring object. But, the image is not enough. Sometimes knowledge of the anatomy, structure, mechanisms of locomotion or other important facts could be an initiation of a new idea. Designers and architects could be inspired by any of the discovered principles.

### 3.5 Reformulation of the identified natural solution

The next phase is a reformulation of the identified natural solution/phenomenon as a possible design solution for the creation of a new product or improvement of existing one. The reformulation means the application of the deduction method in order to transform the description into a set of specific keywords (Table 4). The main intention is the description to become comparable with possible design problems. In this process it is very important to use the appropriate set of key words or short descriptions as answers for the following carefully defined questions:

1. **what?** - the key word that describes the category of natural solution/phenomenon (shape, material, structure, mechanism, energy exchange .....);
2. **purpose?** - The key word that describes the purpose of the natural solution (protection, locomotion, transformation, surviving, energy saving, social behaviour ....).
3. **How?** - a short explanation how the natural solution is performed (rolling into a ball, stretching, layering, covering with plates, segmentation ....).

Table 4: Reformulation of the identified natural solution

Natural phenomena	Description of the identified natural solution	Reformulation of the identified natural solution		
		What?	Purpose?	How?
	Pill millipedes bodies are consisted of eleven to thirteen body segments and are capable of rolling into a ball when disturbed, as a defence against predators.	Body shape	Transformation of the body shape Protection from predators	11 body segments rolling into a ball

### 3.6 Search for design problems where the identified solutions could be applied

The final goal of the process of inspiration for the designer is recognition where to apply the explored natural solution/phenomenon. Searching for the analogy between the identified natural solution and already established human needs is the core of this phase. The comparison as a method for recognition of an analogy between two issues is possible only if they are presented on the same or similar way (Table 5). It means the design problems to be described in the same manner as the natural solutions, with the similar set of appropriate key words, as answers to the same questions:

1. **what?** - the key word that describes the main category of the design problem (shape, material, structure, mechanism, energy exchange .....);
2. **purpose?** - Key word that describes the main purpose (protection, locomotion, transformation, surviving, energy saving, social behaviour ....).
3. The question **how** has to be defined as a result of the search through the list of recognized natural solutions.

The successive comparisons between the keywords of the columns **what** and the columns **purpose** from the list of recognized natural solutions and the list of defined design problems lead towards discovering of an analogy between them. It means identification of a natural solution which could suggest how to solve the defined design problem.

Table 5: Reformulation of the design problem

Description of the design problem	Reformulation of the design problem		
	What?	Purpose?	How?
Adjustable seating equipment, for small sandwich bars, suitable for outside use and protected from external influences.	Equipment for seating	Seating Position adjustment Protection from external influences Easy transportable	Unknown

This process could be performed several times, and several possible solutions could be

recognized. The results could be applied for creation of myriad different concepts.




#### 4. Case studies

Inspiration as a process is completed when the results become visible. Each of the identified and explained steps of the presented strategy could be applied in an innovative and creative way for the phase of concepts generation for the development of a new product or improvement of an existing one.

Product design is a complex process. It usually consists of various steps for solving multiple design problems. All of them have to be properly solved for the process to be completed and to result with a successful final product. Each step of the design process should be treated separately, as a specific design problem.

The following examples illustrate the successful application of the presented strategy in our process of education. During the last five years, students started with a collection of interesting examples of natural solutions. All of them were described in a list of recognized natural solutions. Table 6 presents only an extract from the whole list.

**Table 6: List of recognized natural solutions**

Description of the identified natural solution	Reformulation of the identified natural solution		
	What?	Purpose?	How?
 <p>Lappa Burdock, Arctium (burdock) Asteraceae - Large - leafed plants which growth near forest streams in Macedonia</p>	Large leaves with long petiole	Rain water collection and transfer to the roots  Solar energy used for photosynthesis	Long empty petiole  Large surface
 <p>Onion is a vegetable with round shape, made of layers.</p>	Body strength	Permanent growth	Outside layers
 <p>Ladybugs have a hard case that protects their wings and also protects them from predators. The Elytra is also the part that shows the ladybug's colours and patterns to predators to warn them off.</p>	External shell	Extra hardness Protection from injuries Warning	Symmetric pair of external wings  Warning with colours and patterns

On the other hand, there was an already specified list of defined design problems. Table 7 presents only a few of them.

**Table 7: List of defined design problems**

Description of the design problem	Reformulation of the design problem		
	What?	Purpose?	How?
1. Bicycle children seat with possibility for size adjustment for children of different ages	Children equipment for transportation	Seating Size adjustment Safety	unknown
2. Multifunctional self - sustainable urban shelter	Urban shelter	Rain an Sun protection Rain water collection Solar energy collection	unknown

#### Case study 1

Student 1 had to find a solution for the design problem 1 - design of a bicycle children seat with the possibility for size adjustment for children of different ages. According to the proposed strategy student 1 started with a comparison between the keywords of the columns what and purpose of Table 6 and Table 7. The result was proposed solution for size adjustment of a seat with layers that accommodates different children ages, according to the onion layers - as inspiration (Fig. 1).



Figure 1: Design of a bicycle children seat with possibility for size adjustment for children of different ages

#### Case study 2

Student 2 had to find a solution for the design problem 2 - design of multifunctional self - sustainable urban shelters. According to the proposed strategy student 2 started with a comparison between the keywords of the columns what and purpose of Table 6 and Table 7.

The student recognized that the large leaves of Lappa Burdock, which growth near forest streams in Macedonia, are an excellent example for inspiration. The large leaves have a shape of the surface which could be a solution for the problem protection from external influences. The long empty petiole of this plant is an excellent model for directing the rain water flow - through the petiole (handle) towards the roots of the plant. The result was a design of a multifunctional and environmentally-friendly urban shelter, as an integrated solution which provides not only shade and rain protection, but also generation of electrical energy through the use of solar panels, as well as collection

and storage of rain water for irrigation of the surrounding plants and refreshment with spraying (Fig. 2).

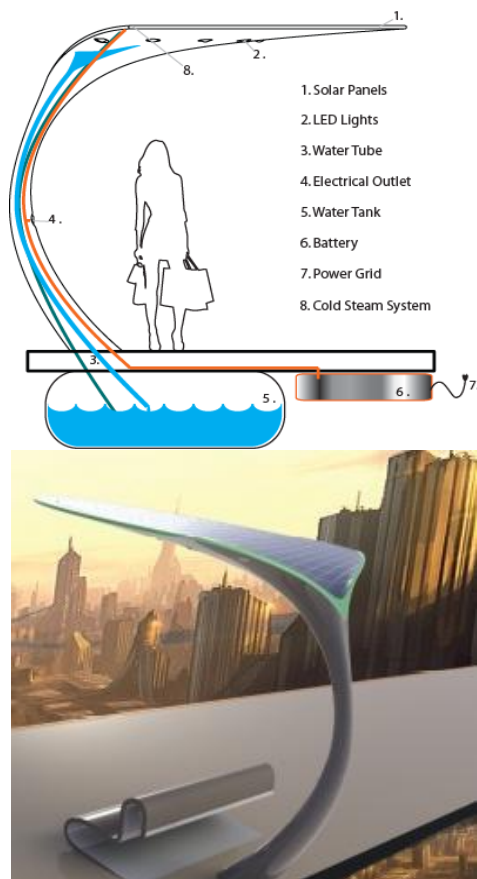


Figure 2: Design of a Multifunctional self - sustainable urban shelter

In conclusion, bionic principles and methods are a great instrument for the designers on their way to innovative approaches in all of the phases of the design process. The process of development of a new product consists of many phases. Most of them could be realized with application of solution-based or problem-based bionics approaches, according to the specific problem.

We hope that we succeed with our research to contribute to the improvement of the bionic design strategy that could be applied in the educational process for improvement of creativity of the design and engineering students. Our main goal was to apply a solution oriented strategy for efficient exploring of nature in the phase of searching for inspiration. The strategy consisted of six steps in the process of

exploring of natural systems followed by an extraction of important core principles, and a structured way of documentation could be a great support for designers in their way of searching for inspiration.

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