Enhancing creativity through Biological Stimuli during new products ideation

Rodrigo Bastos Fernandes
Dept. of Mechanical Engineering, Federal University of Santa Catarina,
Florianopolis, Santa Catarina, Brazil.

André Ogliari
Dept. of Mechanical Engineering, Federal University of Santa Catarina,
Florianopolis, Santa Catarina, Brazil.

Abstract

The development of new and innovative products consists in a competitive advantage, allowing companies to overcome competitors, maintain or even increase its market share. As the product development cycle is shortening, a greater effort is required at the ideation of new technologies and products. In this context, the bio-inspired design has been receiving attention as a creativity strengthening method. However, the majority of methods and tools proposed in this field present biological stimuli in the form of literature extracts, requiring a great cognitive effort from the design teams in abstracting principles to generate ideas. In this paper a systematic approach to biological stimuli development is presented, as well as its contribution during the ideation process. An experiment was conducted on the context of a product design course. As result, it was evidenced that the biological stimulators contributed to the increase of the ideas' utility and variety, favoring the innovation process.

Keywords: creativity; bio-inspired design; product design; product development; engineering education.

1. Engineering education and bio-inspiration

The search for innovation through new and creative products and services consists on a competitive advantage at increasingly global markets and has been the objective of many companies and researchers [16, 18, 27, 29, 50]. Aligned with the market competitiveness, the products life cycles are shortening, demanding the design teams a greater effort to determine market trends in order to anticipate research and development, and to reduce the products time-to-market [12].

For the generation of more and better ideas, which may result in economically successful products, design teams depend on creativity. To promote creativity and to support designers in the process of ideation of new products, many creativity methods can be found in literature (e.g. brainstorming, TRIZ, six hats, synectics). Although these methods present activities and even tools to guide users during the creative process, some researchers observed that individuals tend to use information and to search for solutions in the same domains of knowledge in which they are specialized, being this limitation called psychological inertia [8, 39]. Therefore, the importance of the development and improvement of creativity methods [40] that present and encourage the use of information and stimuli from different domains, as the biological one. Lately, although not recent, the inspiration on biological systems have been gaining the attention of design teams and researchers [13, 21, 33, 41, 42, 45, 46, 47, 51] as the investigations advance on how natural systems work [25] and, mainly, how they are capable of performing actions with efficiency [24]. This field of studies destined to the understanding and application of biological systems characteristics (e.g. functions, materials, structures) as inspiration for ideas generation and problems solving is known as Bionics or Biologically Inspired Design [43, 44, 49].

In effect, there is an increasing number of publications related to bionics [1, 2, 10, 28, 42, 47, 51], which demonstrate the scientific interest and the potential in using biological stimuli to enhance creativity at the ideation phases of product design.

1.1 Bionics and the analogical thinking

In order to generate bio-inspired solutions designers must previously identify relevant biological information that will serve as a basis for the abstraction of principles that, when adapted and applied to the technical domain, are capable of stimulating the generation of new ideas for design problems. This process of information abstraction and its knowledge domain transfer is known as analogy [9, 14]. According to [5], the more distant the domains of information, e.g. the biological and the engineering domains, the greater the effort required to the identification of similarities and to make analogies, resulting in a higher probability of originality and innovation. As presented at the research [9], the information gathered in nature can be applied at the ideation of technical systems in four different ways, as illustrated in Figure 1, according to the abstraction level of the information.

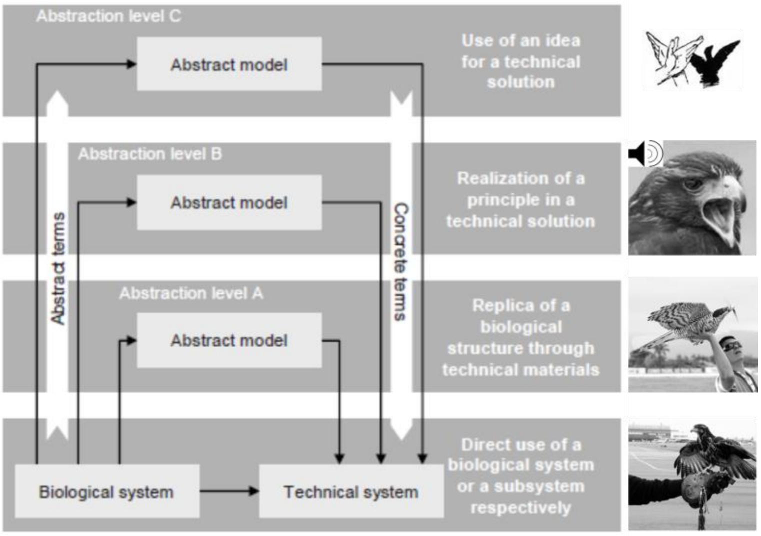

Figure 1. Levels of abstraction of biological information.
(source: [9], pp.167)

The first level of abstraction correspond to the direct use of the biological system for the product design (e.g. trained hawks are being used to evade birds from airport airspace). At the second level, it is suggested the use of morphological or structural characteristics of biological systems [20] to stimulate new ideas for the product design (e.g. the development of an unmanned aerial vehicle that is structurally similar to a hawk). At the third level of abstraction, biological principles should be identified in order to be used as generic stimuli for ideation sessions. Here, principles are considered as the means that allow biological systems to perform a determined and specific action (e.g. animals use sound perception to identify predators - to evade birds from the airport airspace the sound of hawks could be used). Moreover, the fourth level of abstraction is related to ideas or concepts derived from the analysis of the biological system (e.g. the use of hawk's shadow projections to evade birds from an airport airspace).

Along with the proposed levels of abstraction, the individual's perception and cognition varies depending on the form in which the information is presented [23, 39]. In effect, different types of representations (e.g. mind maps, 3D drawings, sketches, mathematical equations) are used by designers, in daily basis, to present and rationalize information and knowledge [19]. Some authors [11, 19, 30] indicate the use of texts as stimuli in order to facilitate both, the biological information understanding and the identification of similarities for the analogical reasoning, as the case of complex biological phenomenon described in natural language discussed at [4]. Others encourage the use of images (e.g. figures, drawings) and objects, arguing that illustrations and visual stimuli present less restraint to the creative process [5, 19].

The fact is, the majority of the stimuli presented by bio-inspired methods are restricted to low abstraction levels [17], residing on the designers capacity of abstraction and analogy making in order to ideate useful, original and creative solutions. [28], for example, proposed a catalog containing a variety of biological systems descriptions with the aim of allowing designers to understand how these systems work. Although the catalog presents visual stimuli, regarding the morphological parts of the biological systems described, and consists itself in a respectful repertoire, the main descriptions are presented in natural language with technical biological terms, which makes its use not practical during ideation sessions. [15], at its turn, also proposed a biological systems catalog but, differently from [28], the descriptions are vague and focus mainly on the morphological characteristics of the biological systems described. Others [3, 29] proposed likewise repertoires containing biological stimuli. The one from [29] is composed only by biological literature extracts from [32], a specialized biological literature, where the possible abstractions to stimulate ideation depend on the designers cognitive capacity. Similarly, the tool proposed by [3], called IDEA-INSPIRE, comprise textual biological systems characteristics described according to the SAPPhIRE model. This model resides on seven description fields (i.e. State-Action-Part-Phenomenon-Input-oRgan-Effect) and, according to the authors, is capable of presenting specific (Parts) and also generalized (change of State) information from a given biological systems [35]. Despite the high-level abstraction affirmation and the presence of the biological system images, little is presented by [3] on which are the principles or how they may be derived from the information presented by the tool.

As pointed by [13], some approaches to the stimuli identification are based on keywords related to biological systems functionalities, as the cases presented by [19, 22, 30]. According to these researchers, the use of functional representations and keywords improves the identification of similarities between the biological and technical systems during the analogical reasoning and the ideation process, improving the quantity and quality of the information transferred from one knowledge domain to another. These evidences are explained by the own objective of the functional representation which is the systems abstraction to the level of task or action capability, regardless the morphological characteristics. Yet, functional keywords point to possible actions that the idealized product may perform and not to solution principles. The principles retrieval still depend on the previous experience and knowledge of the design team.

Aligned with the use of keywords, the BioTRIZ [43, 51], one of the few methods that effectively present bio-stimuli related to the abstraction level of principles [13], is based on the inventive principles. These principles consist of key words (e.g. segmentation, asymmetry), with short explanations in natural language (e.g. segmentation - divide and object into independent parts), related to ways in which a certain contradiction can be solved [36]. The contradictions can be defined as an inversely influence relation between two engineering parameters (e.g. the increase on the stiffness of a structure presents a negatively effect on its weight, i.e. its increase). The use of the inventive principles during ideation sessions was already investigated by [31, 51], who pointed its effectiveness in stimulating feasible concepts.

According to the methods reviewed, it can be noted that the majority is based on biological literature extracts, requiring great cognitive effort of the design teams in order to abstract the biological information in the form of generalized principles, facilitating the analogy making and the idea generation. In addition, the methods that rely on abstracted keywords, as the cases based on functional representation and inventive principles, are the ones most suited to the ideation process. In this sense, requirements for the development of high-level stimuli must be determined.

In this sense, the main goals of this research are to present a systematic approach to the development of generalized biological stimuli, in terms of biological systems contents and principles, and to evidence the creative contribution of the stimuli generated, during design ideation sessions.

2. Biostimulators development process

The process proposed to systematize the development of biological stimulators (BioS) with high abstraction level contents is composed by nine activities, as illustrated in Figure 2.

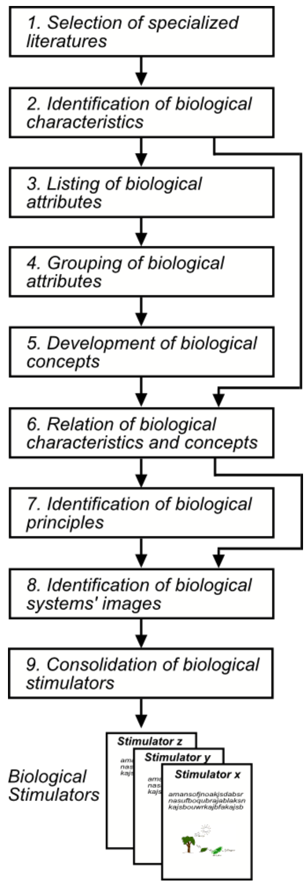

Figure 2. Activities for the development of high abstraction level biological stimulators.

The first activity present as entry information the stimulators development scope, i.e. the determination of what kind of stimulator is to be developed. In the present case, the scope was the development of biological stimulators. In this sense, this first activity regard the selection of specialized literature [24, 25, 37] as the basis for the extraction of biological systems' characteristics. The literature selection criteria proposed are: i) the number of editions - the higher the number of editions, more recent are the updates and higher is the literature demand; ii) the publication year - the more recent the publication, the closest from the state-of-the-art the literature may be; iii) the use of the literature at graduation courses - indirect criterion related to the technical acceptance and academic relevance.

The second activity focus on the identification of biological systems characteristics described at the selected literature contents. The searched characteristics are related to the actions, forms, composition and behaviors presented by the biological systems. Through the literature reading, when a characteristic is identified, the excerpt containing its description and context is registered for further analysis, as presented in Figure 3. The result is a spreadsheet containing literature excerpts with biological systems characteristics.

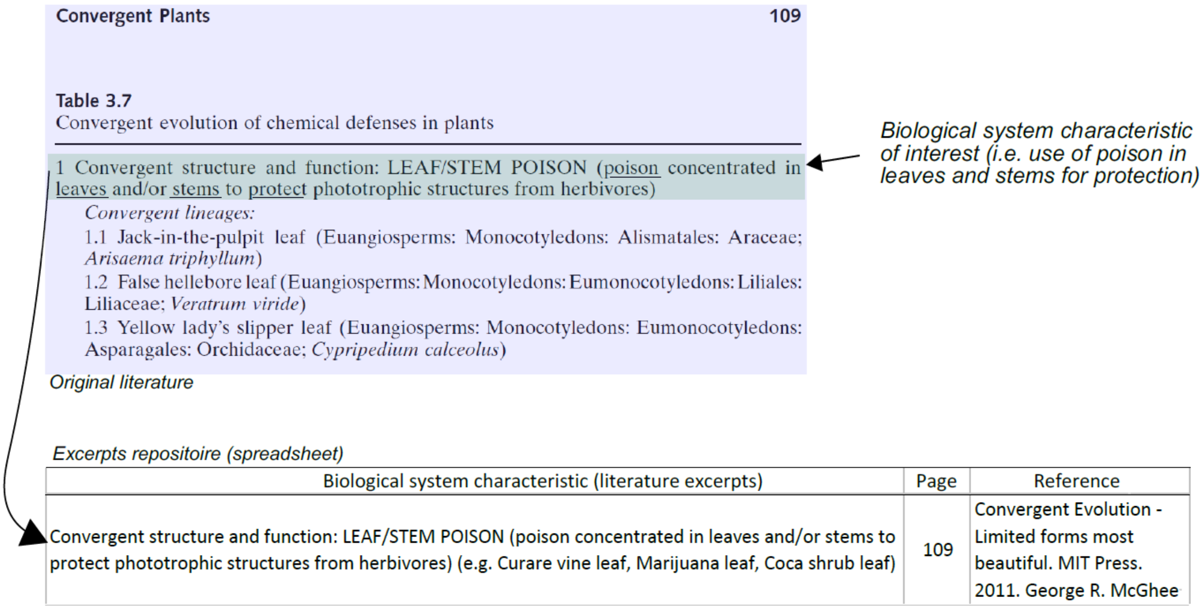

Figure 3. Activities for the development of high abstraction level biological stimulators.

The third activity, based on the registered excerpts, is destined to the attributes' isolation and count. The attributes are words related to the functions (action verbs) performed and the substantives (forms, composition and behaviors) presented by the biological systems. In this manner, by the identification and count of all the attributes present at the excerpts, a list is generated as illustrated in Figure 4. This list will serve as the basis for the generation of abstract biological concepts.

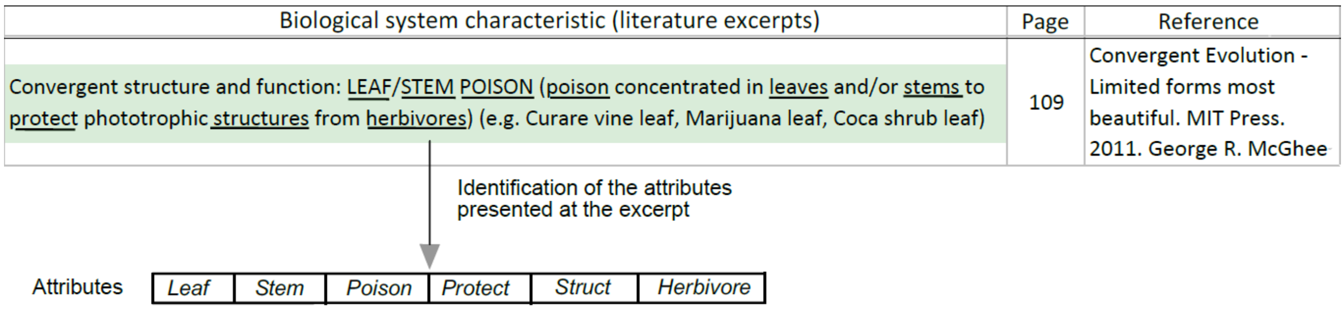

Figure 4. Illustration of the biological attributes presented by an excerpt.

Having the biological attributes list, the fourth activity consists on the clustering those attributes, according to its interdependence, similarity and logical relationship. Due to the specificity of certain attributes and the variety of possible relations, specialists must be consulted in order to evaluate and validate the clusters developed. For each cluster a name must be choosen in the form of a keyword, that represents the logic used for the attributes' grouping, as presented by the example in Figure 5.

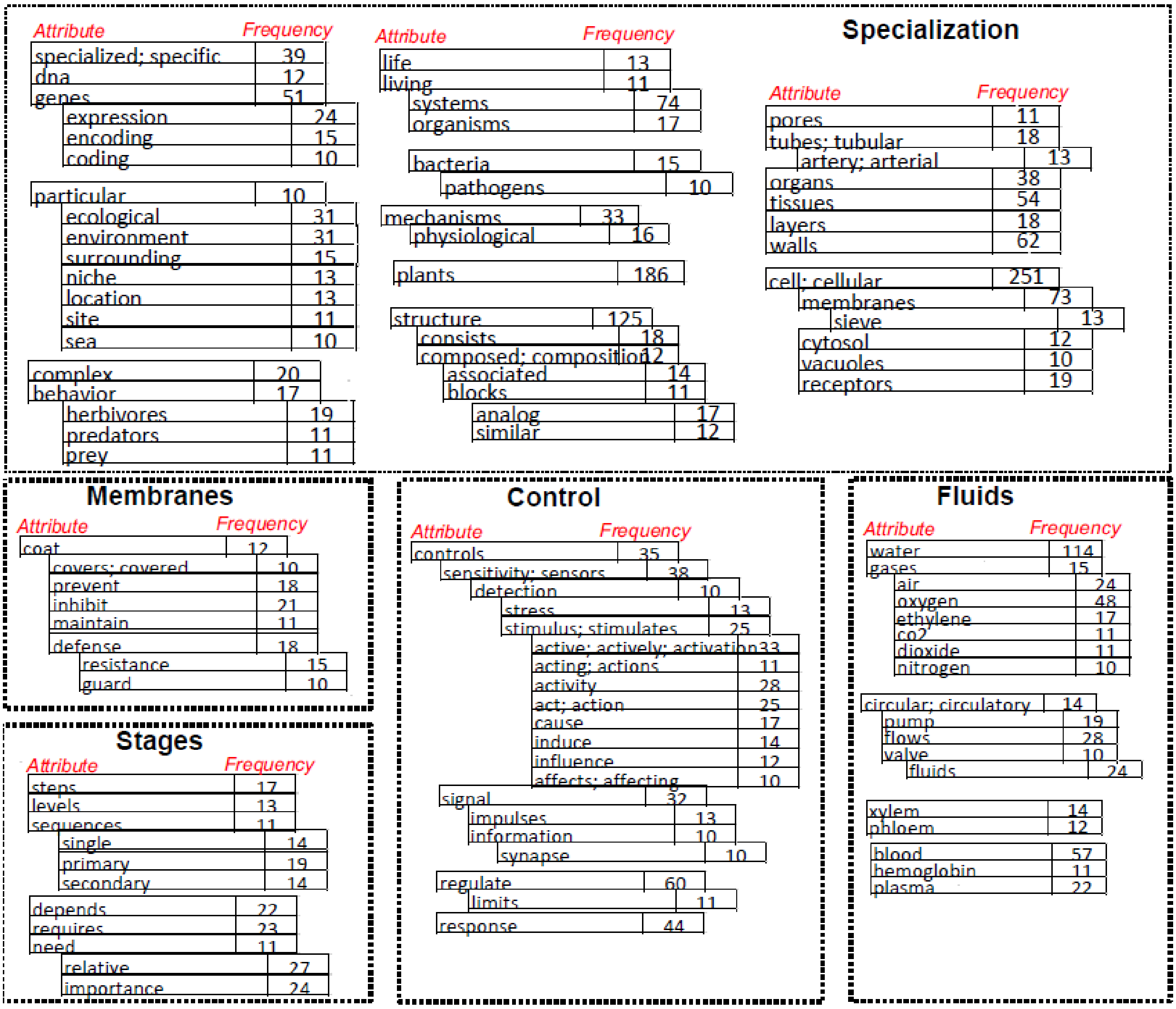

Figure 5. Illustration of some of the clustered biological attributes.

As it can be seen in Figure 5, the attributes were clustered in five groups, each presenting a particular characteristic that was used during the clusterization process. At the example presented, considering the attributes control, detection, signal, response, it was considered that these attributes were related to the logic of Control.

The fifth activity focus on the development of sentences that represent and synthesize the biological systems' characteristics associated with each cluster. As the sentences and the clusters names already summarize biological informations, they can be considered as biological concepts. In order to guide the sentences development, three orientation questions are proposed: i) Which is the main characteristic or relation between the attributes of the particular cluster?; ii) Why the given name (keyword) for the cluster, in fact, represents the biological domain?; iii) How the generalized characteristic (keyword) is encountered in nature?. With the respective answers, the stimuli developer can consolidate a synthetic sentence that will correspond to the biological concept that presents a high abstraction level. In order to facilitate the understanding of such activity, the proposed questions were answered for the Control attributes group:

- Which is the main characteristic or relation between the attributes of the particular cluster? The main characteristics are related with the control parameters.

- Why Control, in fact, represents the biological domain? In nature the biological systems must present a flexible and precise control of their internal processes in order to survive the variable environmental conditions.
- How the Control concept is encountered in nature? The Control concept can be encountered in many biochemical processes (e.g. homeostasis - internal processes equilibrium) and can be represented by the central nervous system.

Having the answers, the biological concept Control can be synthesized as: In nature, for the maintenance of 'life', the environment conditions and the biochemical process must be maintained within certain levels, requiring a flexible and fine control from the biological systems.

At the sixth activity the literature excerpts from activity 2 are confronted with each one of the concepts resulted from the fifth activity. This comparison allow the identification and establishment of particular contents for each stimulator, in terms of examples and principles. As the number of excerpts can be high, and considering that each excerpt contains specific and context related information, the following orientations for the relationships determination are proposed: i) the biological concept defined should cover the information presented by the excerpts; ii) each excerpt must be related to just one biological concept, allowing the abstraction of dedicated contents; iii) the relation between the excerpt and the concept must not be based only on the attributes featured in common, instead, it also must regard the content context. In order to facilitate the understanding of the present activity, an example is presented in Figure 6.

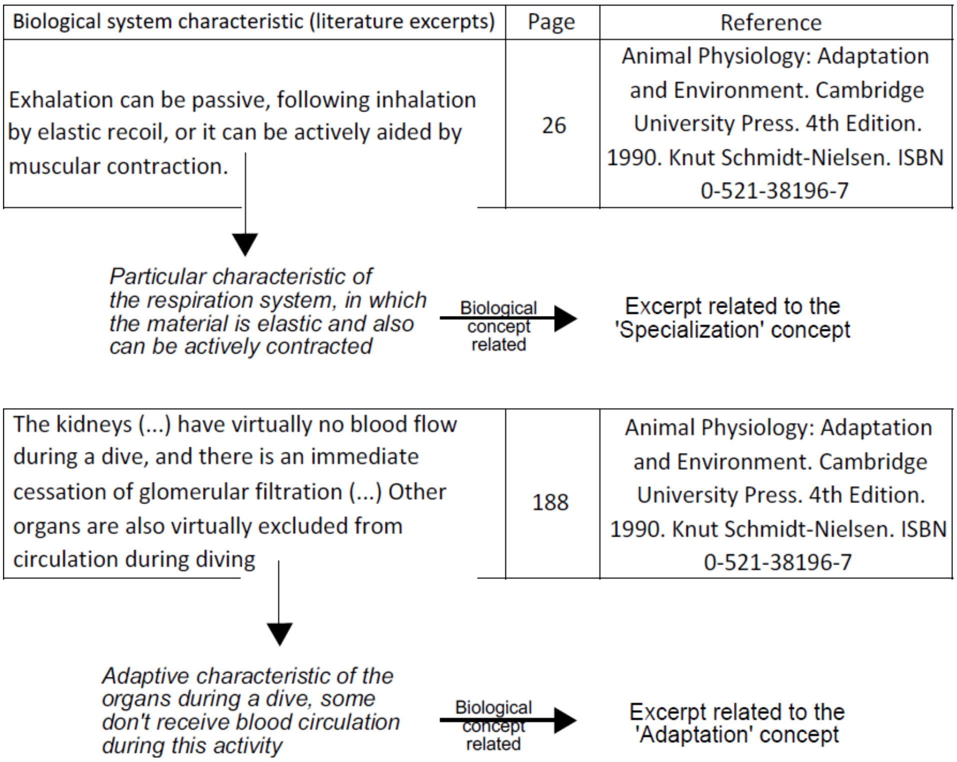

Figure 6. Illustration of the relation between the excerpts of information and the biological concepts.

As it can be seen in Figure 6, two excerpts were interpreted according to its contents and context, one being related to the biological concept specialization, due to the particular characteristic of elasticity and active contraction, and other to the adaptation concept, due to the characteristic of altering its functioning during certain activities.

For the identification of principles as contents for each biological concept, the excerpts related to a given concept must be interrelated, in order to allow the identification of similarities, being this the seventh activity proposed. As the interrelations are conducted, the principles derive from similarities between different systems in terms of functions (actions and behaviors) and characteristics (properties, materials and forms). The higher the number of systems that present a given function and/or characteristic, the more representative and generalized will be the principle abstracted. In order to organize the development of the concepts' contents it is proposed a paired comparison between the excerpts. If similarities are identified at a given comparison, the recurrent characteristic must synthesized in a sentence, without specific technical terms, that may allow the understanding of how the similar biological systems proceed certain action or behavior, or why it presents a given material, form or property. As an example of the identification of similarities between excerpts, the Figure 7 is presented.

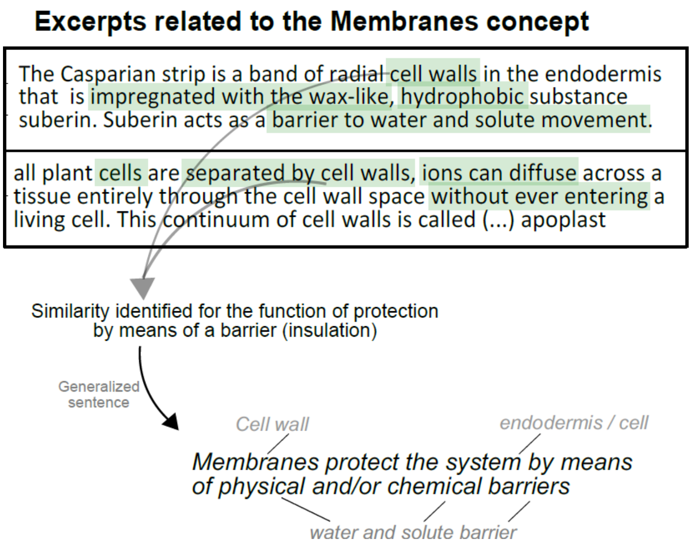

Figure 7. Illustration of excerpts pairing for the information of similarities.

In Figure 7 two excerpts related to the Membrane concept were paired in order to identify similarities between its contents. As it can be seen in the illustration, the two excerpts regard the existence of the cell wall which is as barrier against water and solute (ions) movement. The similarity being identified, the sentence synthesizing the biological principle was: Membranes protect the systems by means of physical and/or chemical barriers.

As images also contribute to the information understanding and retrieval, the eighth activity concern the identification of biological systems images that may facilitate the understanding and applications of the developed concepts and principles. Even though the selected literatures (activity 1) present biological systems images, the present activity aims the identification of generalized illustrations that present a clear relation with the developed concepts and principles, and also can be found in basic biological literature. This last restraint is mainly related to the cognitive factor reviewed, in which the basis for the analogical reasoning and the similarities identification is the individuals' memories and acquired knowledge. That is, images most probably seen by the stimulated users may contribute to the identification of a greater number of memories and, as a result, a positive influence at the creative and ideation process. The two main orientations for the biological systems images identification are: i) the developed concepts and principles must be illustrated by images that concern biological systems identified or cited on the excerpts related to a given concept - the higher the number of citations, the more representative is the system to be illustrated; ii) the images to be chosen to illustrate the concept/principle must preferably be present in basic biological literature and be images that are easily recognized by the general population. In order to illustrate the eighth activity, Figure 8 is presented.

Biological system characteristic (literature excerpts)	Page	Reference
Insects, the most successful terrestrial animals, have a hard cuticle, which is highly impermeable to gases and whose covering wax layer makes it virtually impermeable to water as well.	50	Animal Physiology: Adaptation and Environment. Cambridge University Press. 4th Edition. 1990. Knut Schmidt-Nielsen. ISBN 0-521-38196-7
The insect cuticle is a highly complex organ, which consists of several layers. The hard chitin itself is not particularly impermeable to water; the resistance to evaporation resides in a thin covering layer of wax.	330	Animal Physiology: Adaptation and Environment. Cambridge University Press. 4th Edition. 1990. Knut Schmidt-Nielsen. ISBN 0-521-38196-7
Plant (...) All cells are enclosed in a membrane that serves as their outer boundary, separating the cytoplasm from the external environment (...) transport proteins (...) are responsible for this selective traffic of solutes across the membrane.	6	Plant Physiology. Sinauer Associates, Inc. Lincoln Taiz and Eduardo Zeiger. 4th Edition. 2006. ISBN 978-0-87893-856-8
More mature regions of the root often have an outer layer of protective tissue, called an exodermis or hypodermis, which contains hydrophobic materials in its walls and is relatively impermeable to water.	56	Plant Physiology. Sinauer Associates, Inc. Lincoln Taiz and Eduardo Zeiger. 4th Edition. 2006. ISBN 978-0-87893-856-8
All plant parts exposed to the atmosphere are coated with layers of lipid material that reduce water loss and help block the entry of pathogenic fungi and bacteria. The principal types of coating are cutin, suberin, and waxes	316	Plant Physiology. Sinauer Associates, Inc. Lincoln Taiz and Eduardo Zeiger. 4th Edition. 2006. ISBN 978-0-87893-856-8
The top coating of cuticle wax often crystallizes in an intricate pattern of rods, tubes, or plates (...) enhance water repellency by increasing the roughness of the wax surface (...) "Lotus effect" (Fig. 13.3)	317	Plant Physiology. Sinauer Associates, Inc. Lincoln Taiz and Eduardo Zeiger. 4th Edition. 2006. ISBN 978-0-87893-856-8

Identified biological systems imagens

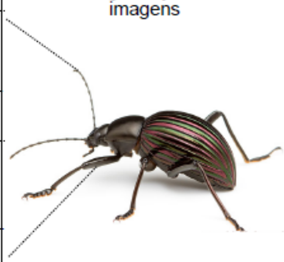

Figure 8. Example of the illustrations identification for the membrane concept.

In Figure 8 the two images identified for the membrane concept were derived from the excerpts of literature presented. One of the illustrations refer to the insects coating (i.e. hard cuticle … impermeable to water and impermeable to gases), cited at the two excerpts. According to the activity orientations, the image identified as representative and easily recognized was a beetle. The second image identified refer to plant membranes to avoid water losses. One of the excerpts considered mention the lotus effect. This being considered, the identified image for the concept was a leaf with water droplets, evidencing the hydrophobic characteristic of the leaf wax coating.

Having the outcomes of the previous activities, the ninth one is destined to the stimuli consolidation, according to the representation principles reviewed. As the BioS aim to contribute to the creative process during ideation sessions, their use in the form of cards was already proved to be effective [17]. In this manner, for each of the biological concepts generated a stimuli card should be consolidated, allowing users to choose and exchange cards during the ideation session.

Through the application of the systematization proposed nine BioS were developed, from which three are presented at the Figure 9.

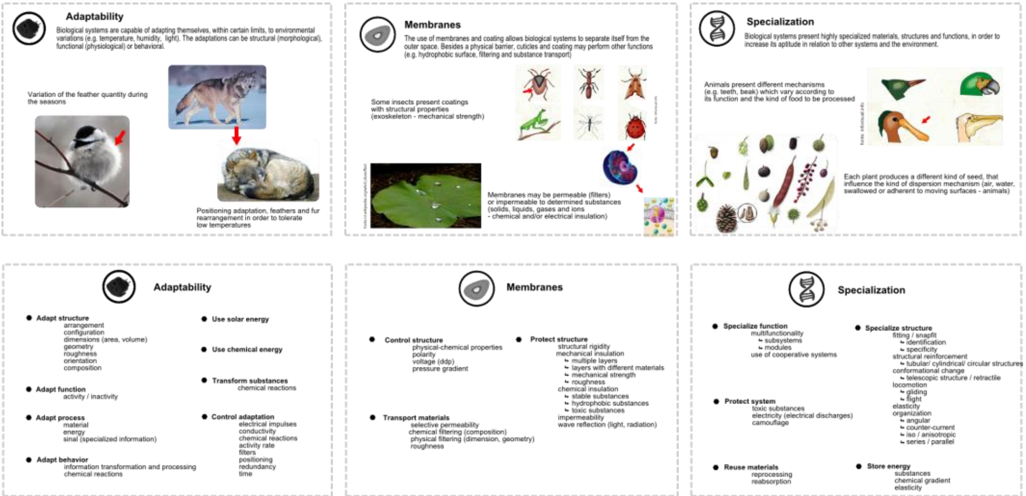

Figure 9. Biological stimulators selected randomly and applied at the experiment.

As it can be seen at Figure 9, the BioS cards developed are composed by two parts, one for the biological concept description along with some illustrated examples, and the other for the biological principles identified, presented in the form of keywords. The images selected can be related do the abstractions level 'A' (Figure 1), due to the possibility of identification and replication of morphological and structural characteristics of the biological system illustrated. In the case of textual stimuli, keywords related to principles were identified and presented in the form of topics. These keywords can be directly related to the abstraction level 'B', where principles (ways in which a functions can be performed) can be used to solve a problem. In addition, the concepts developed can be related do the abstraction level 'C', due to its high level abstraction.

3. Experiment setup

In order to quantitatively assess the creative contribution of the biological stimulators developed according to the systematization proposed, a hypothesis test [6, 26] was conducted with Mechanical Engineering undergraduate students, in the context of the Product Design course in the Spring of 2013.

The main hypothesis tested was that the BioS developed according to the systematization proposed favor the generation of more and better ideas, as the inspiration in nature can contribute to the ideation of solutions that would not be thought if the individuals focused the attention only in their domains of expertise (psychological inertia).

The independent variable considered for the test was the presence or absence of the BioS during the ideation session. The dependent variables, considered as metrics for the quantitative analysis, also used in other researches [7, 34, 38, 48] were:

- Quantity: measured by the number of ideas generated;
- Utility: measured by the number of functions that the ideas is meant to perform (i.e. the higher the number of functions, the higher the ideas utility);
- Variety: measured by the number of features presented by the ideas (i.e. the higher the number of features, the higher the ideas variety).

Here, a higher number of ideas and ideas presenting a higher utility and variety are considered beneficial for the product development process, as these characteristics contribute to the increase on the number of possible and better problem solutions.

The hypothetical problem proposed was related to houses located at inundation risk areas, for which the students were asked to generate ideas to prevent indoor material losses. The students were randomly separated in groups of three members, resulting in 16 groups in total. The experiment structure can be seen in Table 1.

Table 1. Experiment organization

Creativity method	Groups organization	
Traditional brainstorming (TB)	Groups 1 to 8	-
Traditional brainstorming + BioS	-	Groups 9 to 16

According to Table 1, all groups practiced the traditional brainstorming as the creativity method, but just half of the groups was stimulated by the BioS (i.e. stimulated by generalized biological information) as contributions for the ideation process. In order to avoid unwilling information exchange between the groups during the ideation session, the groups that were stimulated by the BioS (i.e. groups 9 to 16) were physically separated from the control groups (i.e. groups 1 to 8) in different rooms.

Considering the restraints for the experiment conduction (i.e. time and human resources), the authors randomly selected three of the nine BioS developed to stimulate half of the groups of participants during the experiment. The use of only three of the BioS did not influence the analysis conducted, as the experiment objective was to verify the creative contribution of generalized biological information as stimuli during the ideation process, and the three BioS randomly chosen did present the information required. The BioS applied at the experiment are the ones presented at Figure 9. The activities involved in the experiment can be seen in Table 2.

Table 2. Experiment organization

Activity		Time	Instrument and/or Additional Information
1	Problem presentation	5 min	Brainstorming rules; problem explanation
2	Groups definition	5 min	Random groups formation; separation of the groups; distribution of the ideas' registry form
3	Presentation of the BioS	5 min	Orientations for the use of the BioS during the ideation session, only for the groups 9 to 16
4	Ideation session	45 min	Time destined for the ideas generation

As shown in Table 2, the proposed problem and the basic rules of the brainstorming were presented in the beginning of the session for all the participants. Having the groups randomly formed, the ideas' registry form was distributed. In order to facilitate the posterior analysis, the groups were asked to detail the ideas generated with a sketch and a small textual description, evidencing the functions performed and the features included in each idea (see Figure 10).

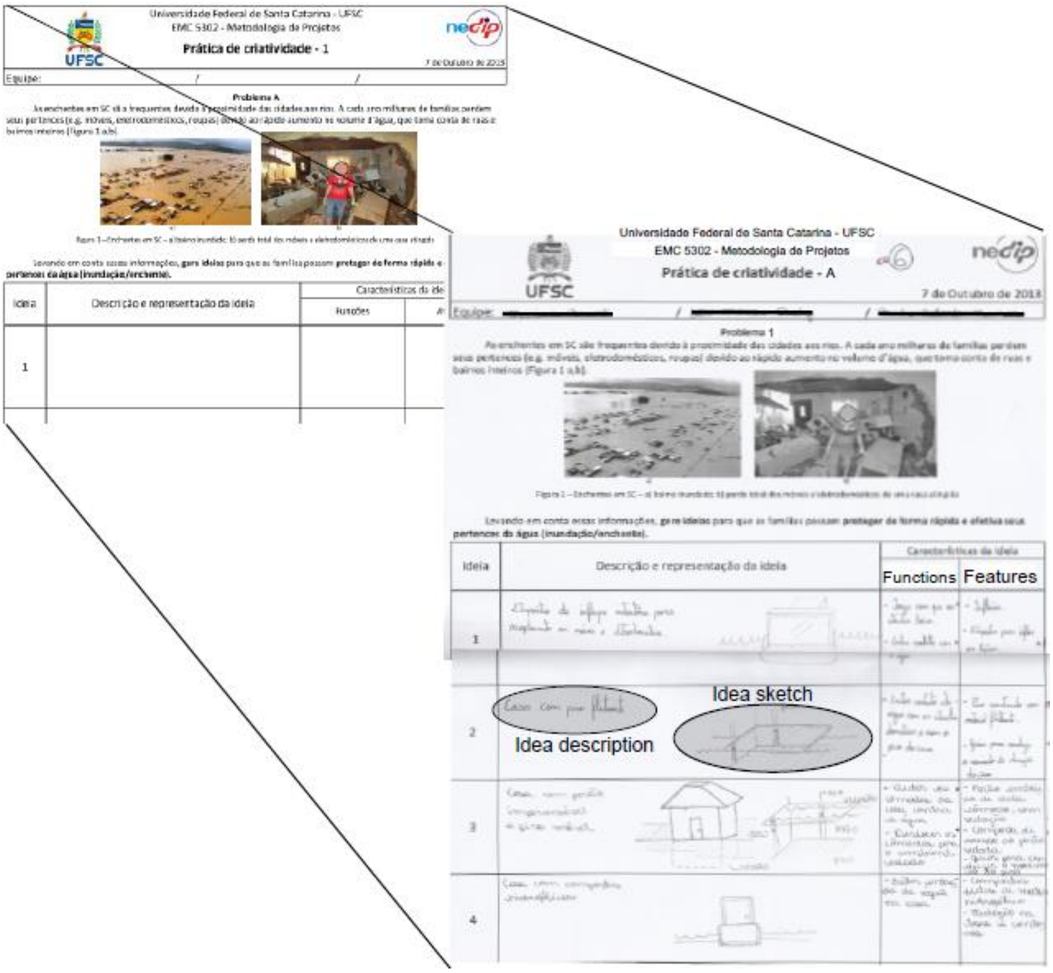

Figure 10. Ideas registry form.

After the separation of the groups, the biological stimuli were presented only to those who would use them and the cards of the three BioS were given for each group. As a recommendation for the BioS use, the groups were told to read them completely before the ideas generation, in order to acknowledge its contents. Also, it was recommended that the cards should be maintained visible for all the group members during the ideation process.

The ideas gathered at the registry forms were analyzed by two experienced researches in product design. The statistical methods used to evaluate the hypothesis were the analysis of variance (ANOVA) and the Wilcoxon--Mann--Whitney test [6, 26], selected according to the Anderson-Darling normality test. The statistical significance level was defined as 10 % (i.e. 90% of reliability for the hypothesis tests results).

4. Results

The data obtained in the experiments are presented at the Table 3.

Table 3. Data obtained at the experiment

Number of:	Groups															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Values obtained for each metric															
Ideas	9	12	10	11	7	7	8	9	9	11	12	11	11	11	8	8
Functions	6	12	6	7	5	5	6	8	13	11	11	12	16	9	12	10
Features	17	26	22	33	11	29	14	16	21	12	17	18	13	23	18	19

The statistical analysis conducted to identify the differences between the teams stimulated by the BioS and the teams that performed the traditional brainstorming session, without external stimuli, are presented in Table 4.

Table 4. Results obtained through the experiment

Metric	Statistical method	p-value	Interpretation
Quantity	Wilcoxon-Mann-Whitney	0,14	No significant influence on the number of ideas generated by the use of BioS was identified
Utility	Wilcoxon-Mann-Whitney	**0,00**	The use of BioS influenced significantly the number of functions presented by the ideas generated – BioS favor the increase of the ideas' utility
Variety	ANOVA	**0,07**	The use of BioS influenced significantly the number of features presented by the ideas generated – BioS favor the increase of the ideas' variety

As it can be seen at Table 4, despite the non-significant contribution of the BioS to the proposition of a higher number of ideas, the experiment evidenced that the use of BioS do promote the ideas' utility, favoring the designers to think, include or, at least, consider more and different functions to be executed by the solutions generated. This finding is compatible with natures' characteristic of efficiency (e.g. structures or processes capable of performing different actions according to the systems state and/or the environmental changes). One example of idea generated during the experiment ideation session is presented at Figure 11.

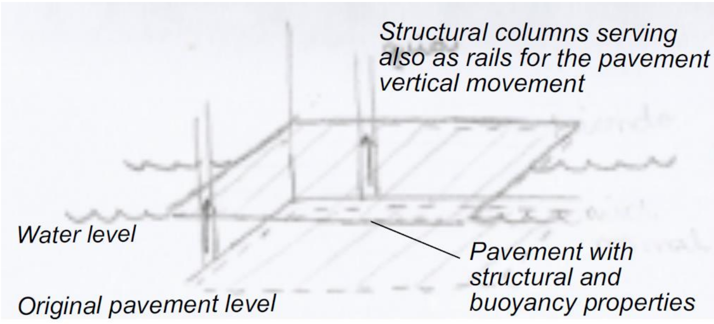

Figure 11. Example of an idea presenting the characteristic of multi-functionality.

According to Figure 11, the idealized solution for the inundation problem was that the house pavement could also present buoyancy properties, being that, when the water level starts to rise, the pavement supporting all the indoor items would float and avoid losses. In addition, the house structural columns would serve as rails for the pavement vertical movement, as it starts to float with the water level increase.

Also, as highlighted at Table 4, the use of the BioS contributed to the increase of ideas' variety. As the BioS present generalized concepts along with representative biological images, the designers are stimulated to ideate solutions that comprise a higher number of features (e.g. features related to biological morphological characteristics), adapting biological characteristics to technical systems, which is the essence of the biological-inspired design.

5. Discussions and further research

The systematization proposed allowed the development of high-level abstraction contents (i.e. BioS) which, through an experimental test, presented a significant creative contribution to the ideation process in terms of utility and variety of the ideas generated. In effect, the BioS presented themselves capable of reducing the designers' cognitive effort in applying biological information for problem solving. The reduction of cognitive effort may directly influence the design team's decision in applying certain methods and stimuli during ideation process. In this fashion, the authors consider that the BioS resultant from the systematic approach where adequate to strengthen the analogical thinking, contributing both to the use and dissemination of the bio-inspired design, and to improve creativity.

Regarding the bio-inspired methods and tool revised, the systematic approach present a structured and guided process to designers and researchers to develop adequate biological stimuli to strengthen creativity and the ideation process. Apart from the other low-level of abstraction bio-stimuli, the BioS present a variety of abstracted informations, in the form of keywords, principles and illustrations that are able to stimulate individuals that have different preferences and cognitive abilities regarding the analogical thinking process. Therefore, the resultant biological stimulators augment the probability of analogies formed by the designers, the quality of the ideas generated, as well as ideas with more or different functionalities and features. As utility and variety are two of the main value delivers perceived and searched by users and by the market on new products, technologies or services, the biological stimulators proposed have much to contribute to the innovation process.

The authors consider the proposed systematization as a first step for the development of better ideation stimuli and for the increase on the use of biological information at the product development. As the researches on the BioS continue, refinements on the systematization and on the BioS are expected, as well as the increase on the number of BioS and in the ways in which they can be used during ideation sessions (e.g. software and smartphone applications). In addition, the authors suggest that the systematic approach proposed might be applied or adapted to other fields of knowledge (e.g. chemistry and physics), which may contribute as well to creativity and the ideation process.

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