DO BIOMIMETIC STUDENTS THINK OUTSIDE THE BOX?

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Abstract

Biomimetics is a recognized method in ideation for getting access to new and – for the designer – novel knowledge, which hopefully will result in more novel and useful products. But do designers actually find new knowledge, i.e. think outside the box or do they stick to well-known biological phenomena? If they concentrate on animals and plants, which they beforehand have knowledge about, it could be expected that solutions will remind of what they would have found without using biomimetics. To investigate this question, the empirical results from a university course in biomimetics have been analysed. The empirical material comprises 111 students working on 28 different functional design problems. On average teams identify 9.0 relevant biological phenomena and manage to produce a physical proof-of-principle for the selected biological analogy. 39% of the analogies can be characterised as well-known phenomena and 51% are from the animal kingdom. These numbers indicate a tendency of fixating on well-known knowledge. The authors propose that applying a simple constraint during the search process can counteract the tendency.

Keywords: Bio-inspired design / biomimetics, Creativity, Early design phases

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1 INTRODUCTION

Biomimetics is a recognized method in ideation for getting access to new and – for the designer – novel knowledge. Using biological inspiration is claimed to result in more novel and useful products. However, a concern for practitioners could be the time consumption in getting familiar with the method and the likelihood of finding relevant new solutions. Another possible criticism arises when designers do not identify good novel solutions. When designers do not find really novel solutions a viable explanation could be their possible fixation on to them well known biological phenomena. If they concentrate on animals and plants, which they beforehand have knowledge about, it could be expected that solutions will remind of what they would have found without using biomimetics. To investigate these questions, the empirical results from a university course in biomimetics have been analysed. The empirical material comprises 111 students working on 28 different functional design problems. The results indicate that it is realistic to learn the method within a timeframe of 2-3 weeks. On average teams identify 9.0 relevant biological phenomena and manage to produce a physical proof-of-principle for the selected biological analogy. It is found that a wide variety of biological organisms have been examined even though 51% of the analogies belong to the animal kingdom and 39% of the analogies can be characterised as well-known phenomena. These numbers indicate a tendency of fixating on well-known knowledge and hence reduce the likelihood of proposing novel solutions to the design problem. The author proposes that this tendency can be counteracted by applying a simple constraint to the search process, namely that biological phenomena should be identified from different categories, e.g. animals, plants, insects, fungi, cell biology, micro-biology and ecology.

1.1 Literature review

Several authors describe how biomimetics is used for identifying relevant interesting biological phenomena in nature and used for novel way of solving technical problems (Lakhtakia and Martín-Palma, 2013; Shu et al., 2011; Vincent and Mann, 2002). Helms and colleagues describe a method for performing biomimetic design work. Functional analysis of the design problem is amongst other tools facilitated including the 4-box method that focus on operational environment, function, specifications and performance criteria (Helms and Goel, 2014; Helms et al., 2009). Shu addresses the search challenge and terminology differences between the biology and engineering domain and describes a search method facilitating search in biological literature (Shu et al., 2011). Hashemi describes how better results can be achieved when engineers and biologists collaborate (Farzaneh, 2016). The web based Asknature recommends the use of a biomimetic taxonomy to focus the functional analysis and an online database for finding relevant biological analogies (Biomimicry Institute, 2016). The biocard method recommends functional analysis using sketching and a combination of application specific and generalised description of functional problems and search words (Keshwani et al., 2013; Lenau et al., 2010; Lenau et al., 2015). Search can be done using a variety of sources including library searches and observations in nature. Biological analogies are described on so-called biocards that encourages the user to clearly describe central functional solution principles using text and graphics. Ahmed-Kristensen and colleagues describe the limiting role of design fixation where designers narrow their possible solution space because they are locked in well-known patterns (Ahmed-Kristensen et al., 2013; Ahmed and Christensen, 2009). They see biomimetics as one possible approach to avoid design fixation since analogies found in nature are far analogies.

1.2 Goal for the study

The overall goal for the present study is to investigate how easily users pick up biomimetics and to identify possible obstacles that can limit the use of the method. Learning the basic biomimetic method is probably not more difficult than learning other design methods. However, there are factors that make the use more complex. The method requires that time is spent on different knowledge sources – preferably scientific literature, which also introduce a challenge: terminology and mindset. Biology uses a lot of special words and the purpose of a biology article is normally to understand a phenomenon and not how it can be applied for design. But despite these challenges the method is being used and the study looks at how well the methods is received in a biomimetic course. To this end the following hypothesis 1 is formulated:

It is realistic within a short timeframe to identify relevant analogies in nature and verify their usefulness for practical problems.

People that learn biomimetics are not always successful in finding good and relevant analogies and using them for proposing novel and useful designs. One reason could be that users get fixated on topics they are familiar with and omit to make a broader search that would lead them into unknown land. To investigate this question results from the biomimetic courses are analysed for type of found analogies, weather the analogy can be characterised as well known and if the resulting proposed solution can be regarded as a useful solution to the initial design problem. The following hypothesis 2 is formulated:

Designers are fixated on biological phenomena they know beforehand and it is therefore less likely that they will come up with useful solutions.

2 METHOD

The empirical material used is a result from a 3-week intensive graduate course. The students work full time on the course in the 3-week period in groups of 3-4 persons. The majority of students come from design engineering but they also include medical engineering, material science, mechanical engineering and biology. The course is project-oriented and the students select a functional problem and apply the biomimetic method in order to solve the problem. The theoretical basis for the course is the previously described biocards method (see Figure 1) combined with elements like the 4-box method from Georgia Tech. Functional problems are analysed by drawing the problem, making the 4 box description and discussing it within the group. Search words are formulated based on a generalised formulation of the functional problem. Search is carried out as a combination of database searches in Asknature.org, EOL.org and the on-line Findit facility at the DTU Library. A more detailed understanding of the phenomena is then achieved by reading relevant journal papers and books found at the library. Design principles are identified from biological analogies, communicated on biocards (see Figure 2) and verified using tests of physical models. Each group makes 8 biocards and veryfy one principle. The rough time schedule for the course is 2 days for introduction, 6 days for biomimetic search, analysis and biocards and 7 days for building physical models and testing. Course results are documented in reports and on posters, which is presented at a final presentation.

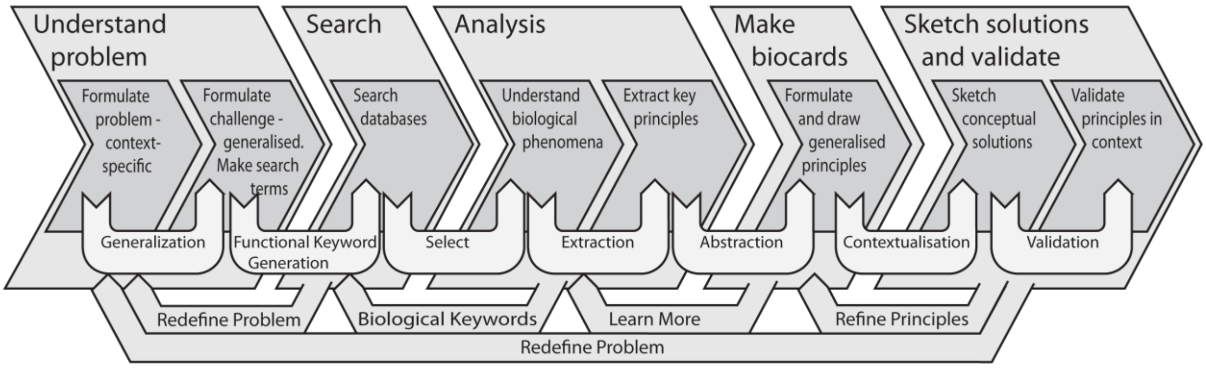

Figure 1. The five phases in the biocard method as used in the course

Student reports and posters have been used to identify the functional problem, the found biological analogies (formulated as biocards with textual and graphical descriptions) and the physical models and proposed applications. The material includes results from 2 years' courses that represent 28 concrete cases with very diverse functional problems. Biocards have been characterised as describing animals, plants, insects, other biological phenomena and phenomena from outside the biological world as seen in table 1+2. The categories are fairly broad: Animals cover mammals, amphibians and birds. Plants include all organisms with photosynthetic metabolism and fungi. Insects include most arthropods, e.g.

with 6, 8 or more legs. Other biological phenomena could be single cell organisms, cell biology and microbiology. Ecological topics are placed in the category of the dominating organism, e.g. termite mounds under insects. The category non-biological covers analogies, which are not living, e.g. hard diamonds, layered shale and how ice brake up on water. The classification of whether the biological phenomena is well-known and the selected solution is useful is based on a subjective judgment of the author.

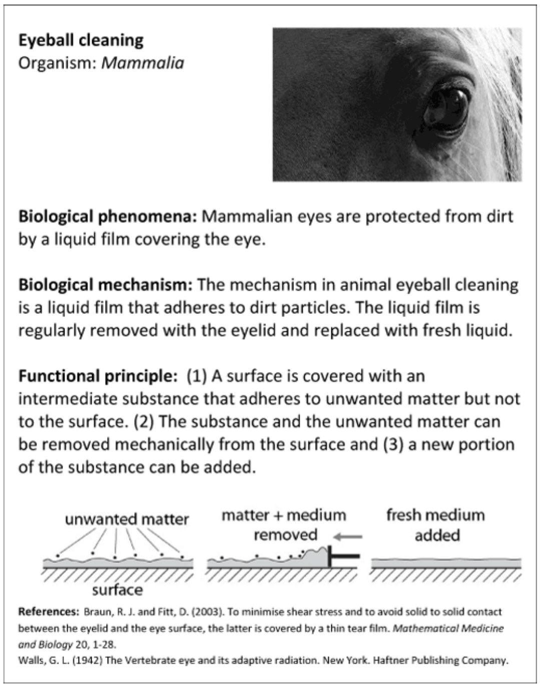

Figure 2. A biocard describing a biological phenomenon and the relevant function, an explanation of the mechanism and a description of the generalised principle and drawing

3 RESULTS

The biomimetic course in 2015 had 61 participants and in 2016, 50 participants. They formed 15 respectively 13 groups with 3-4 participants in each group. Each group selected a functional problem from a catalogue prepared for the course. The students are further required to select an application case of own choice to enable a more precise search. For example, did group G15-1 focus on how to further decrease brake length for cars by developing a new type of emergency brake. The functional problems and selected cases can be seen in table 1+2. These tables also describe the final selected biological analogy and the physical model that was used for validation. Further they describe an assessment on a scale from 1-3 of how useful the proposed solution is for solving functional problem in the given case.

Based on a biomimetic search each group found a number of biological analogies which they described using biocards. As seen in table 3 total of 252 analogies (=biocards) were found. Each group found on average 9.0 analogies. 99 analogies (39%) were assessed as being well known, which equals 3.5 analogies per group. 12 groups proposed solutions that were ranked highly useful. Almost all of these groups based the solutions on biological analogies that were considered not well known. In contrast the majority of the groups with solutions that were ranked less useful were based on well-known analogies.

Table 1. Functional problems, selected analogies and physical models from 2015

Number	Functional problem – selected case	Selected biological analogy	Physical model	Solution useful 1=low 3=high
G15-1	Quick and strong attachment - Reduction of brake length	Snail slime	Model size vehicle and sticky substances	3
G15-2	Wet attachment – non-invasive fishing	Remora fish directional suction	Suction cup, lever and slimy surfaces	3
G15-3	Skin penetration – medical needles	Porcpine barbed quill	Barbed oversized needles	3
G15-4	Eatable insects – harvesting bee drones	Platypus grinding + flamingo feed filtering	Freeze bee larvae + filtering	2
G15-5	Selective light reflection – solar cells on roofs	Window plant	Mirror sided small tubes for angular dependency	2
G15-6	Colour change – mobile covers	Cuttlefish double layers + butterfly structural colours	Double layers, thin layers and magnetic particles	2
G15-7	Low energy cooling – bomb protection suit	Air and liquid circulation in wolf pads and elephant ears	Circulating liquid in clothes + cooling ribs	3
G15-8	Silent motion on ground – railroad tracks	Human porous bone + Indian stick vibration damping	Metal tubes with different filling	2
G15-9	Silent motion in air – fans	Owls: winglets, leading and trailing edges	Fans with added winglets and changed edges	2
G15-10	Detection of weak sound signals – finding survivors	Bat and owl ears, fruit fly antennas	Cones and tubes	1
G15-11	Detection of weak smells – sensing skin cancer	Dog nose	Collector shape and ph-paper	1
G15-12	Movement underground – tunnel digging	Wood wasp ovipositor	Wooden saw-like jaws and sand basin	3
G15-13	Fireproof yet degradable – disposable grill	Banksia seeds and termite mound material	Egg shells and sand + organic binder	3
G15-14	Self-healing – bicycle tire	Blood clotting veins	Coaxial layers of plastic bags,	3
G15-15	Heat generation and regulation – egg hatching	Compost heap + birds feathers	Foamed PS box + heating element	2

Table 2. Functional problems, selected analogies and physical models from 2016

Number	Functional problem – selected case	Selected biological analogy	Physical model	Solution useful 1=low 3=high
G16-1	Selective light reflection – solar cells in wearables	Butterfly selective reflection	Thin layer interference	2
G16-2	Off-grid motion – venetian blinds	Sunflower motion & kangaroo tendons	Phase change energy storage	1
G16-3	Non-metalic electric conductance – jelly wire	Jellyfish extracellular ionic matrix	Saltwater gel	3
G16-4	Divide into smaller pieces – materials recycling	Carpenter bee vibration	Vibration induced breakage	1
G16-5	Self-sharpening – lawnmower blade	Sea urchin teeth with hard and soft layer	A hard core with a soft cover	1
G16-6	Stiff structure in soft materials – umbrella	Sun flower stem cell pressure	Pneumatic stiffeners	1
G16-7	Impact protection – suitcase	Arapaima fish scales	Stiff scales + absorbing layer	3
G16-8	Motion in mud – boots	Octopus suction cup	Cup shaped protrusions	1
G16-9	Low energy cooling in buildings – high rise buidling	Sea star absorbs cold water to increase thermal inertia	Cold water reservoirs limits temperature rise	2
G16-10	Olfactory medical diagnosis – smelling tuberculosis	Dog nose detect faint odours du to air channel geometry	Nose like organic shaped air vessels for accumulation of odour particles	3
G16-11	Self-cleaning filters – industrial filters	Celia in lungs create movement of particles	Perpendicular small fibres mounted on the clean side of a filter moves particles	3
G16-12	Dehumidifying damp rooms – private house cellars	Hydrophobic surfaces on feathers repels water	Paterned hydrophobic coatings on glass plates	2
G16-13	Firm grip on varying surfaces – a single legged chair	Seal fur directional friction	Short rubber hairs	3

Table 3. Analysis of biocards

	# of biocards								
	animal	**plant**	**insect**	**other bio**	**non bio**	**total**	**well known analogies**	**final well known 1=yes 0=no**	**Solution useful 1=low 3=high**
G15-10	9	0	2	0	0	11	7	1	1
G15-11	2	1	2	0	0	5	2	1	1
G16-4	6	0	3	1	1	11	3	0	1
G16-5	6	1	0	0	2	9	5	1	1
G16-6	3	4	1	0	0	8	6	1	1
G16-8	6	1	1	0	0	8	4	1	1
av.	**5,3**	**1,2**	**1,5**	**0,2**	**0,5**	**8,7**	**4,5**	**0,8**	
G15-4	3	1	2	0	0	6	1	1	2
G15-5	2	4	1	1	0	8	2	0	2
G15-6	1	2	4	0	0	7	3	1	2
G15-8	3	1	2	0	0	6	2	1	2
G15-9	6	1	1	0	0	8	5	1	2
G15-15	2	0	2	3	0	7	5	1	2
G16-2	4	7	1	1	0	13	2	1	2
G16-1	4	1	3	0	0	8	4	1	2
G16-9	7	2	4	0	0	13	7	0	2
G16-12	4	4	2	0	0	10	2	1	2
av.	**3,6**	**2,3**	**2,2**	**0,5**	**0,0**	**8,6**	**3,3**	**0,8**	
G15-1	4	2	4	0	0	10	4	0	3
G15-2	9	0	0	0	0	9	5	0	3
G15-3	4	2	6	0	0	12	3	0	3
G15-7	2	1	2	0	0	5	2	0	3
G15-12	4	2	2	0	0	8	3	0	3
G15-13	5	6	5	0	0	16	4	0	3
G15-14	5	3	0	1	0	9	2	1	3
G16-3	6	0	0	3	0	9	2	0	3
G16-7	6	1	1	0	0	8	4	0	3
G16-10	3	2	2	1	0	8	2	0	3
G16-11	6	0	6	0	0	12	4	0	3
G16-13	6	1	1	0	0	8	4	0	3
av.	**5,0**	**1,7**	**2,4**	**0,4**	**0,0**	**9,5**	**3,3**	**0,1**	
# cards	**128**	**50**	**60**	**11**	**3**	**252**	**99**		
% of all	**51%**	**20%**	**24%**	**4%**	**1%**		**39%**		
av. of all	**4,6**	**1,8**	**2,1**	**0,4**	**0,1**	**9,0**	**3,5**		
# 0	**0**	**6**	**4**	**20**	**26**				

4 DISCUSSION

In total 111 participants working in 28 groups have passed the course in a 2-year period. They have all succeeded in finding relevant biological analogies and verifying the underlying principles using physical models. This illustrates that it is feasible to learn the biomimetic mind-set and method to a level where students can use it independently. The basic training in the method is done within 1,5 weeks, but the remaining 1,5 week where physical models are made and tested most likely also play an important role for the refinement of the skills in applying the method.

The present paper aims to investigate how well designers think out of the box when using biomimetics for ideation in design work. 51% of the biocards described biological phenomena from the animal kingdom compared to only 20% for plants, 24% for insects and 4% for other biological phenomena. All groups consider animals, while some groups did not look at plants or insects. A majority of groups did not consider other biological phenomena. This indicates a preference for animals. A possible reason could be a general empathy for animals – they are similar to us, and we often read our own feelings into their behaviour. Another reason could be that there is much easy-accessible information available about animals ranging from popular videos to easy-to-grasp popular literature. This is at least true on a phenomenological level. However, the detailed mechanisms and principles that explain the phenomena can be more difficult to understand since a more detailed reading of scientific biological literature is required. This is even more the case for plants and insects, where the scientific literature can be more difficult to understand, e.g. the morphology and terminology is not as familiar to many as it is for animals. For other biological phenomena like single celled organisms or cell biology the scientific literature can be even harder to understand for non-biologists.

Another interesting finding is the ratio of well-known biological phenomena. 39% of the biocards represent phenomena that are well known to the author, and from discussions with the students during the courses it is apparent that many of them were also well known to the students. It is off course fine to be inspired by well-known biological phenomena and very good product solutions can result. But the high percentage indicates a fixation on the well known which can limit the fraction of really novel ideas. This is further confirmed when looking on the usefulness of the resulting solutions (judged subjectively by the author). Almost all the best solutions were based on principles from previously unknown biological phenomena.

Even though some biological topics are harder to understand they should not be left out of the biomimetic process. The likelihood of finding really new ideas is greater when working in unknown territory. It is therefore proposed to apply a constraint on the biomimetic process to make sure to cover the breath. This could be as simple as requesting that phenomena are found within all of the overall biological categories animal, plants, insects and other biological phenomena.

REFERENCES

Ahmed-Kristensen, S., Christensen, B. T. and Lenau, T. (2013), Naturally Original: Stimulating Creative Design Through Biological Analogies and Random Images. In *Proceedings of the ASME 2013 International Design Engineering Technical Conferences*. Portland,Oregon.

Ahmed, S. and Christensen, B. T. (2009), An In Situ Study of Analogical Reasoning in Novice and Experienced Design Engineers. *Journal of Mechanical Design*, *131*, 111004–1. http://doi.org/10.1115/1.3184693

Biomimicry Institute. (2016), AskNature - Innovation Inspired by Nature. Retrieved December 19, 2016, from https://asknature.org/

Hashemi Farzaneh, H. (2016), *Bio-inspired design: Ideation in collaboration between mechanical engineers and biologists*. Technische Universität München.

Helms, M. and Goel, A. K. (2014), The Four-Box Method: Problem Formulation and Analogy Evaluation in Biologically Inspired Design. *Journal of Mechanical Design*, *136*(11), 111106. http://doi.org/10.1115/1.4028172

Helms, M., Vattam, S. S. and Goel, A. K. (2009), Biologically inspired design: process and products. *Design Studies*, *30*(5), 606–622. http://doi.org/10.1016/j.destud.2009.04.003

Keshwani, S., Lenau, T. A., Ahmed Kristensen, S. and Chakrabarti, A. (2013), BENCHMARKING BIO-INSPIRED DESIGNS WITH BRAINSTORMING IN TERMS OF NOVELTY OF DESIGN OUTCOMES. In *INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED13*. Seoul: Design Society.

Lakhtakia, A. (Akhlesh) and Martín-Palma, R. J. (Raúl J. . (2013), *Engineered biomimicry*. Elsevier.

Lenau, T., Dentel, A., Invarsdottir, T. and Gudlaugsson, T. (2010), ENGINEERING DESIGN OF AN ADAPTIVE LEG PROSTHESIS USING BIOLOGICAL PRINCIPLES. *11th International Design Conference (Design 2010),* 331–340.

Lenau, T. A., Keshwani, S., Chakrabarti, A. and Ahmed-Kristensen, S. (2015), BIOCARDS AND LEVEL OF ABSTRACTION. In *Proceedings of the 20th International Conference on Engineering Design (ICED15)* (Vol. nn). Milan: Design Society.

Shu, L. H., Ueda, K., Chiu, I. and Cheong, H. (2011), Biologically inspired design. *CIRP Annals - Manufacturing Technology*, *60*(2), 673–693. http://doi.org/10.1016/j.cirp.2011.06.001

Vincent, J. F. V. and Mann, D. L. (2002), Systematic technology transfer from biology to engineering. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *360*(1791), 159–173. http://doi.org/10.1098/rsta.2001.0923