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INFLUENCE OF INFORMATION AND KNOWLEDGE FROM BIOLOGY ON THE VARIETY OF TECHNICAL SOLUTION IDEAS

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Abstract

Bio-inspired design aims at the development of novel, creative solutions with the potential for innovative technical products. It implies the use of different information sources, such as research publications or videos, and knowledge from biology. The influence of information and knowledge from biology on the variety of solution ideas as one criterion for creativity remains to be examined. In this work, we therefore analyse the impact of information and knowledge from biology on the variety of solution ideas generated by pairs of biologists and mechanical engineers working in uni-and bi-disciplinary pairs. The results show a positive influence of information and knowledge from biology on the variety of solution ideas. Moreover, they indicate the need for a support of biologists and mechanical engineers to effectively increase the variety of solution ideas on different levels of abstraction.

Keywords: Bio-inspired design and biomimetics, Creativity, Collaborative design

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1 INTRODUCTION

Technical product development aims at developing innovative solutions for technical problems (Lindemann 2009). One approach to develop creative and ultimately innovative technical solutions is bio-inspired design: The analogical use of information and knowledge from biology is supposed to lead to novel, creative technical solutions. But is that true?
In this work, we examine the influence of different sources of information about biological systems such as research publications or videos, and personal biological or technical knowledge on the variety of solution ideas. Variety serves as one criterion for creativity as explained in a literature review in section 2. Our research approach is based on the analysis of design experiments with biologists and engineers working in uni-disciplinary and bi-disciplinary pairs. The detailed experiment and analysis approach is explained in section 3. The results are shown in section 4: Based on an analysis of the solution ideas on different levels of abstraction (4.1), the influence of the use of information sources and knowledge on the variety of the solution ideas is analysed. The implication of the results for future work is discussed in section 5.

2 LITERATURE REVIEW: CRITERIA AND MEASURES FOR DESIGN CREATIVITY

In psychology research, the two criteria *novelty* and *appropriateness* or *value* are common measures for creativity (Amabile and Hennessey 2010). The same result provided Sarkar and Chakrabarti's analysis of more than 160 definitions of creativity (Sarkar and Chakrabarti 2008). Consequently, Sarkar developed measures to assess the *novelty* of a solution by comparing it to existing products and its *value* (translated into *usefulness*) by rating its importance, popularity and duration/ frequency of use (Sarkar and Chakrabarti 2011). Other researcher regard *quantity* and *variety* in addition to *quality* (comparable to *value*) and *novelty* (Shah and Vargas-Hernandez 2003). Lopez-Mesa and Vidal assess *novelty, variety, quantity* and *feasibility* (Lopez-Mesa and Vidal 2006).
Comparing the different measures, *value, usefulness* and *quality* are related to the fulfilment of goals and requirements by a technical solution or product. Independent of creative aspects of a product, the fulfilment of requirements and goals is a significant part of product development processes, e.g. (Lindemann 2009, Pahl et al. 2007).
On the other hand, *novelty* is a prerequisite for the patentability of a product (Gassmann and Bader 2007) and its innovativeness (Wahren 2004, Hauschildt and Gemünden 2011). Quantity and variety are related measures – to assess the quantity of solutions, the solutions need a certain variety. A certain quantity of solutions is required for achieving a high variety of solutions. Srinivasan and Chakrabarti found a relation between the variety and novelty of conceptual solutions: If designers developed a high variety of concepts, these were also highly novel (Srinivasan and Chakrabarti 2010).

3 RESEARCH APPROACH

Bio-inspired design – the use of analogies from the biological domain to develop technical solutions – aims at developing creative and ultimately innovative solutions. Bio-inspired design encompasses the use of information and knowledge about biological systems. In this work, we examine how the use of information and knowledge from biology directly influences the creativity of solution ideas. To regard the use of information and knowledge from biology, we conducted design experiments with biologists and mechanical engineers using different information sources. As a measure for creativity, we regard the variety of the solution ideas, as it is linked to the quantity and the novelty of solution ideas (see section 2.1). Moreover, the outcome of our design experiments with a duration of 40 minutes are solution ideas documented as simple sketches. On this conceptual level, a comparison to existing products for evaluating novelty can lead to mistakes. The significant criteria value, quality or feasibility have to be assessed separately, this is out of the scope of this work.
Therefore, we pose the following research question: How does the use of information and knowledge about biological systems influence the variety of solution ideas developed in ideation workshops with pairs of biologists and mechanical engineers?
The detailed experimental methodology and the analysis approach are explained in the following sub-sections. The results are presented in section 4.

3.1 Experimental methodology

In the following, we describe the selection of participants, the materials used during the experiments and the experimental procedure.

3.1.1 Participants

Biologists and mechanical engineers participated in the study. The participants were research assistants at several institutes from different areas of biology and mechanical engineering of the authors' university. Since each participant had a different research topic for their doctoral thesis, it is assumed that each participant had a different area of expertise. All design experiments were conducted with pairs of two participants. Each participant first worked with another participant from his discipline on one design task. Subsequently, each participant collaborated with one participant from the other discipline working on another design task.

3.1.2 Materials

All pairs received a design task and three types of information sources providing biological information: a video, a Wikipedia article and a research publication. The different information sources were used to replicate realistic sources of information in bio-inspired design and creative ideation in general: In an internet search, a designer can encounter and access these sources of information. Moreover, they vary in the amount of text and pictures: The selected videos consist of pictures and in some cases verbal comments. The Wikipedia articles and research publications include both pictures and text. In addition, the amount of verbal information is low in the selected videos, higher in the Wikipedia articles and highest in the research publications. Inversely, the videos contain few technical terms, the Wikipedia articles more and the research publications most.

The design task included a textual description, in two cases an illustrative figure, and the task itself. The task was described by a sentence of the form "develop a solution to …" It was followed by the instructions to develop as many solutions as possible and to document them by annotated sketches. Two or three requirements were given.

In this work, two different design tasks as well as two different videos, Wikipedia articles and research publications are analysed. The design tasks and information sources are summarized in Table 1.

Table 1. Design tasks and information sources

design task	**task description**	**publication**	**Wikipedia article**	**video**
water pump	"Develop a solution for lowering a water pump with hose and supply cables down a well."	Wong, W.-L., Gorb, S.: *Attachment ability of a clamp-bearing fish parasite, Diplozoon paradoxum (Monogenea), on gills of the common bream, Abramis brama*, The Journal of Experimental Biology 216, p. 3008-3014, 2013.	byssus (sea shell)	praying mantis: http://www.youtube.com/watch?v=K-RmXhH1gfo&feature=share_email
sun protection	"Develop a solution to prevent the heating of rooms due to solar insulation."	Ishay, J.S. et al.: *The solar cell in hornet cuticle: nanometer to micrometer scale*, Journal of Electron Microscopy: 49 (4), p. 559-568, 2000.	iris (eye)	sunflower: http://www.youtube.com/watch?v=g8mr0R3ibPU

3.1.3 Experimental procedure

The participants first collaborated in a uni-disciplinary pair and then a bi-disciplinary pair. Each design experiment had a duration of 40 minutes which was announced to the participants. The duration of 40 minutes was chosen to represent an ideation session with high time constraints as it is expected in industry. The participants were given the material (printed design task, lap-top with video and

Wikipedia article and printed research publication) and paper, pens and highlighters. The design experiment was recorded on video.

3.2 Analysis approach

The design experiments were recorded on video and transcribed. The coding scheme developed in previous work was used to identify the creation, development and documentation of solution ideas (Hashemi Farzaneh et al. 2013). For this work, utterings related to the discussion of information and knowledge about biological and technical systems were added to the coding scheme. This allowed to relate the use of information and knowledge about biological systems (e.g. from one of the given information sources) and about existing technical systems to the creation of solution ideas.

To calculate the variety of solution ideas, (Shah and Vargas-Hernandez 2003) identify solution ideas on decreasing levels of abstraction, from *physical principles, working principles, embodiments* to *detailed designs*. They count the number of solution ideas on each level and assign a weighting, so that the number of solution ideas on a more abstract level counts more for the variety score.

Srinivasan and Chakrabarti classify the solution ideas according to levels of the SAPPhIRE model (2010). They calculate the variety of solution ideas by counting the number of ideas on each level of the SAPPhIRE model. Similar to Shah and Vargas-Hernandez' approach, the levels are weighted, so that variety on a more abstract level of the SAPPhIRE model is considered higher variety (Srinivasan and Chakrabarti 2010).

The levels of abstraction of both approaches are comparable. Table 2 shows the levels of abstraction used in both approaches in decreasing order. The highest level of abstraction is *action* in Srinivasan & Chakrabarti's approach (2010) which is similar to function used by Shah and Vargas-Hernandez (2003). However, they compare sets of solution ideas fulfilling different *functions* separately. As to *physical phenomenon* and *physical principle*, both approaches describe natural laws. Comparing *physical effect* (Srinivasan and Chakrabarti 2010) and *working principle* (Shah and Vargas-Hernandez 2003), the approaches concentrate on different aspects: Srinivasan & Chakrabarti's physical effect (2010) focusses on the control of the natural law on the system-environment interaction, e.g. heat transfer between system and environment. Shah and Vargas-Hernandez' working principle (2003) describes the concrete implementation of the natural law, e.g. a movement can be implemented as rotation or translation. Shah and Vargas-Hernandez (2003) use two levels of abstraction, embodiment and detailed design, for describing the parts used by Srinivasan and Chakrabarti (2010). Shah and Vargas-Hernandez (2003) do not explicitly regard state change, input and organ.

Table 2. Levels of abstraction to measure the variety of solution ideas (decreasing order)

Srinivasan & Chakrabarti 2010	**Shah &Vargas-Hernandez 2003**
action: abstract description or high-level interpretation of an interaction between a system and its environment	**function**
state change: property of the system (or its environment) that is involved in an interaction	*not explicitly regarded*
input: physical quantity/ variable that crosses the system boundary, and is essential for an interaction between the system and its environment	*not explicitly regarded*
physical phenomenon: interaction between the system and its environment **physical effect**: principle of nature that underlies and governs an interaction	**physical principle** **working principle**
organ: properties and conditions of the system and its environment required for an interaction between them	*not explicitly regarded*
part: set of physical components and interfaces that constitute the system of interest and its environment	**embodiment** **detailed design**

In this work, we concentrate on qualitative aspects instead of focussing on the calculation of a value for variety. Moreover, the data from the design experiments are verbal protocols and preliminary sketches. Therefore, a very detailed assignment of solution ideas to all abstraction levels used by Srinivasan and Chakrabarti (2010) would require a considerable amount of interpretation during the analysis. Instead, we focus on analysing the solution ideas on the *action/ function* level and on the level of *physical principle/ phenomenon* and count the number of solution ideas on these levels. The level of *parts* or *embodiment/ detailed design* can be regarded as well. However, the analysed solution ideas all differ on this level. The results are shown in the following section.

4 RESULTS

In this section, we show the results of the analysis of the solution ideas generated in the 40 min design experiments with pairs of biologists and/ or mechanical engineers. The variety of solution ideas for the tasks *fixation of water pump* and *sun protection* introduced in section 3.1 is analysed. To start with, the solution ideas are analysed (section 4.1). Then, the influence of information and knowledge from biology on the variety of the solution ideas is regarded (section 4.2).

4.1 Variety of solution ideas

We analysed the solution ideas generated for the tasks *fixation of water pump* and *sun protection* by a pair of biologists, mechanical engineers and a bi-disciplinary pair of one biologist and one mechanical engineer. Not all of the solution ideas were documented in conceptual sketches; some were taken from the transcription of the verbal conversation. Table 3 shows the solution ideas identified by the authors on the function/ action level and on the physical principle/ phenomenon level. The solution ideas on the level of *parts* or *embodiment/ detailed design* are not shown, as almost all solution ideas differed on this level.
The same observation as in previous work was made: Each solution idea can address one or several functions/ actions and consequently one or several physical principles/ phenomena. They are therefore no complete concepts fulfilling an overall function as defined by (Lindemann 2009) but partial solutions to possible sub-functions. For example, the solution idea shown in Figure 1 addresses the function *adapt to different cable/ hose diameters* of the water pump by using the physical principle *form closure* and the structure of the praying mantis's leg shown in the video given to the participants.

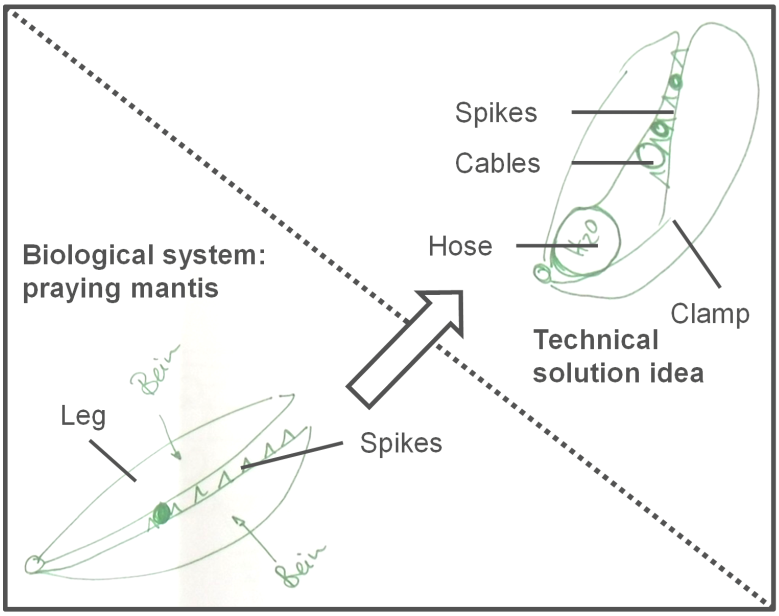

Figure 1. Sketch of one of the solution ideas

Table 3. Solution ideas on different abstraction levels

Task	function/action level	physical principle/ phenomenon level
fixation of water pump	• tighten cables/ hose • loosen cables/ hose • prevent slipping • allow for a number of cable/ hose diameters • adapt to different cable/ hose diameters • set pump on a plate	• form closure • friction • elastic deformation • chemical deformation • vacuum • chemical adherence • gravity
sun protection	• shield heat • shield sun • adapt to temperature • adapt to insulation • adapt to sun position	• absorption • reflection • deflection • interference • coefficient of thermal expansion • osmotic pressure • heat exchange • brownian motion • algae growth • object shadow

4.2 Use of information and knowledge from biology

After identifying solution ideas on the function/action and on the physical principle/phenomenon level, we regard the use of information and knowledge from biology for the generation of these solution ideas. The result is depicted in Table 4 (fixation of water pump) and Table 5 (sun protection). They show which knowledge or information inspired each pair to generate a specific solution idea. We differentiate between information from one of the given information sources (publication, video, Wikipedia article) and additional technical or biological knowledge of the participants. This knowledge is not related to the information sources. One example is knowledge about the gecko which inspired the pair of biologists to generate a solution idea with suction cups (physical principles/ phenomena: vacuum, elastic deformation).

On the function/ action level, the right column of both tables shows that most solution ideas were inspired by several sources of information and biological or technical knowledge. Only one function/ action per problem was inspired by only one information source (video). On the physical principle/ phenomenon level, the result is different: Five of the seven solution ideas for the fixation of the water pump are inspired by a single information source or a single piece of biological/ technical knowledge only. Six of the ten solution ideas for the sun protection are inspired by a single information source or a single piece of biological/ technical knowledge only.

In conclusion, more information or knowledge increases the variety of solution ideas on the level of physical principles/ phenomena, not on the level of functions/ actions. On the parts/ embodiment/ detailed design level, all solution ideas varied; therefore no conclusions can be drawn here with regards to an increase of variety. However, the solution ideas were designed in analogy to the information source that inspired them. This can be seen in Figure 1 – the technical solution idea resembles the praying mantis' leg which served as inspiration. Comparing the different information sources and the individual biological or technical knowledge of the participants, all equally inspired singular solution ideas. No information source or individual piece of knowledge seem to be more "inspiring" than another.

Table 4. Fixation of water pump: Inspiration for solution ideas on different abstraction levels (p=publication, v=video, w=Wikipedia, b= individual biological knowledge, t= individual technical knowledge)

Solution ideas	**biologists**	**mechanical engineers**	**mechanical engineer + biologist**	∑
function/action level:				
tighten cables/ hose	✓ (b, p, w)	✓ (t)	✓ (t, v)	b, t, p, v, w
loosen cables/ hose	✓ (b, p, w)	✓ (t)	✓ (t, v)	b, t, p, v, w
prevent slipping	-	✓ (t)	✓ (b, t, w)	b, t, w
allow for a number of cable/ hose diameters	✓ (v)	-	-	v
adapt to different cable/ hose diameters	✓ (b, p, v, w)	✓ (t, p, v)	-	b, t, p, v, w
set pump on a plate	-	✓ (t)	-	t
∑	4 (b, p, v, w)	5 (t, p, v)	3 (b, t, v, w)	
physical principle/ phenomenon level				
form closure	✓ (v,w)	✓ (t, p, v)	✓ (t, v)	t ,p, v, w
friction	-	-	✓ (v)	v
elastic deformation	✓ (b, p)	-	-	b, p
chemical deformation	-	✓ (t)	-	t
vacuum	✓ (b)	-	-	b
chemical adherence	✓ (w)	-	✓ (w)	w
gravity	-	✓ (t)	-	t
∑	4 (b, p, v, w)	3 (t, p, v)	3 (t, v, w)	
parts/ embodiment/ detailed design level				
∑	12	9	7	

Moreover, we observe that the variety of the solution ideas increases with the decreasing level of abstraction: On the function/ action level, the pairs reached a variety of three to five solution ideas. On the physical principle/ phenomenon level, the variety varied from three to seven. On the parts/ embodiment/ detailed design level the variety was highest – it varied from seven to 12 solution ideas per pair.

Comparing the different pairs, there are no apparent differences between the pairs of biologists, engineers and the bi-disciplinary pairs. All pairs use at least two information sources for generating solution ideas and at least technical or biological knowledge. Using all three information sources for the generation of solution ideas does not necessarily lead to a higher variety of solution ideas.

Table 5. Sun protection: Inspiration for solution ideas on different abstraction levels (p=publication, v=video, w=Wikipedia, b= individual biological knowledge, t= individual technical knowledge)

Solution ideas	biologists	mechanical engineers	mechanical engineer + biologist	∑
function/action level:				
shield heat	✓ (b, t)	✓ (t)	✓ (p)	b, t, p
shield sun	✓ (t, p, w)	✓ (b, t, v, w)	✓ (b, p, v, w)	b, t, p, v, w
adapt to temperature	-	✓ (t, v, w)	✓ (t, w)	t, v, w
adapt to insulation	✓ (b, t, p, w)	✓ (b, p)	✓ (b)	b, t, p, w
adapt to sun position	-	-	✓ (v)	v
∑	3 (b, t, p, w)	4 (b, t, p, v, w)	4 (b, t, p, v, w)	
physical principle/ phenomenon level				
absorption	✓ (t, b, p, w)	✓ (p)	✓ (p)	b, p, v, w
reflection	✓ (p)	✓ (t)	✓ (p)	t, p
deflection	-	-	✓ (w)	w
interference	-	✓ (p)	-	p
coefficient of thermal expansion	-	✓ (v)	✓ (w)	v, w
osmotic pressure	-	✓ (v)	-	v
heat exchange	✓ (b)	-	-	b
brownian motion	-	-	✓ (t)	t
algae growth	-	-	✓ (b)	b
object shadow	-	✓ (t)	✓ (b, w)	b, t, w
∑	3 (b, t, p, w)	6 (t, p, v)	7 (b, t, p, w)	
parts/ embodiment/ detailed design level				
∑	10	9	10	

5 DISCUSSION

This work has a number of limitations which affect the conclusions which can be drawn: The overall number of analysed solution ideas is 57 (on the parts/ embodiment/ detailed design level) – this allows for drawing conclusions regarding the effect of the information sources and personal knowledge on the variety of the solution ideas. However the number of designer pairs is only six - therefore no valid comparison between the pairs of biologists, mechanical engineers and bi-disciplinary can be made. In our sample, there are no apparent differences between the pairs, but further pairs have to be regarded to draw any valid conclusions.

6 CONCLUSION AND OUTLOOK

In this work, we regarded the influence of different sources of information (publication, video, Wikipedia article) and individual biological and technical knowledge on the variety of solution ideas as one criterion for creativity. We compared different pairs of designers conducting a creative solution search: pairs of biologists, pairs of mechanical engineers and bi-disciplinary pairs of one biologist and an engineer. We conducted design experiments with six pairs of designers working on two different design problems in a typical setting for a short creativity session of 40 minutes duration.
As a result, our research question "How does the use of information and knowledge about biological systems influence the variety of solution ideas developed in ideation workshops with pairs of biologists and mechanical engineers?" can be answered:
Information from publications, videos and Wikipedia articles equally resulted in additional solution ideas on the level of physical principles/ phenomena which increases the variety on this level. The individual biological and technical knowledge of the participants also lead to a higher variety of solution ideas. When comparing the different pairs of participants, no differences could be identified. All pairs generated a higher variety of solution ideas on the lower levels of abstraction – the highest variety occurred on the parts/ embodiment/ detailed design level.

This result provides evidence for improving the use of information sources and individual knowledge to increase the variety of solution ideas: In particular on the level of physical principles/ phenomena, information sources, such as those regarded in this work, have a high potential to increase the variety of solution ideas. However, designers have to be supported to more effectively use information sources and individual knowledge to increase variety on this level.

In future work, further pairs of designers have to be regarded to allow for a better comparison between the pairs of biologists, mechanical engineers and the bi-disciplinary pairs. This will show if the different pairs use the information sources more or less effectively for generating a high variety of solution ideas. It will also allow to analyse the pairs' use of the different information sources video, Wikipedia article and scientific publication more specifically. Consequently, such a comparison can show if the inclusion of biologists into the search for bio-inspired solution ideas is a benefit. As most approaches for bio-inspired design currently rely on the search of biological inspirations by (mechanical) engineers without consulting biologists directly, this is an interesting field to explore.

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