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On designers' use of biomimicry tools during the new product development process: An empirical investigation

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As technological problems and societal challenges become increasingly complex, designers are urged to recombine knowledge from different sources in order to innovate. In this paper we question how nature may be the key source of inspiration and whether it can impact the new product development (NPD) process. We shed new light on whether designers and researchers are: first, familiar with biomimicry tools; second, aware of their characteristics; third, in favor of using biomimicry tools in the NPD process; fourth, able to assess the impact of biomimicry tools on the NPD performance. By analyzing survey data, counterintuitive results emerged both concerning the awareness of the biomimetic tools and their impact on the NPD innovation outcomes.

Keywords: biomimicry tools; tools awareness; new product development; comparative analysis

Introduction

Companies are constantly struggling with two exogenous tensions: on the one hand, economic and political pressures to conceive environmentally sustainable products and to address this concern at the very early stages of the new product development (NPD) process; on the other hand, technological and market pressures forcing companies quickly to readapt their organizational routines as consumers' needs become increasingly heterogeneous. These two reasons are convincing companies to look outside their boundaries when searching for new ways of doing things. According to

Benuys (1997), there is no other source to look at more inspiring than nature. This novel way of producing in a sustainable manner in order to be efficient and innovative at the same time is called ‘biomimicry’ (De Pauw et al., 2015). There are many examples of products inspired by nature that span many industries: Velcro, discovered by Georges de Mestral, now used for ties and straps, or general purpose adhesive-backed fasteners; the Eastgate building center in Zimbabwe inspired by the anthill structure; wind turbines inspired by humpback whales (Von Gleich et al., 2009). But what is biomimicry all about and how has it gained momentum as a research field?

Biomimicry is an innovation method that seeks sustainable solutions by emulating nature’s time-tested patterns and strategies. Biomimicry, as a research field, is achieving particular prominence through an explosion of new discoveries in biology and engineering (Lepora et al., 2013). This growth is mirrored in the academic field judging by the increasing number of publications in scientific journals, and in the market judging by the number of patents published. The Da Vinci Index 2.0 measures activity in the field of bioinspiration in the U.S. mainly focusing on the number of academic articles, number of patents, number of grants, and dollar value of grants. Recent statistics show an average annual growth of the index by 18%, climbing by more than sevenfold in the last three years since 2000.

If outlooks on this field show interesting figures, insights on the biomimicry process are still lacking. Perhaps the main reason can be found in its inherent complexity. In fact, the biomimicry process creates an interface between two distant knowledge domains: engineering and biology. Such a distance generates two main problems: 1) engineers’ lack of knowledge on biological phenomena; 2) challenging transfer of natural phenomena into the technical domain. Biomimicry design tools came to life with the aim of solving these problems helping designers along the phases of the

NPD process. However, only few contributions investigate applications of such tools in real-world NPD processes, which could prove the tools' effectiveness (Fu et al., 2014; De Pauw et al., 2014).

This paper attempts to start filling this gap by carrying out an exploratory study. The aim is collecting data from design practitioners asking them if they are familiar with existing biomimicry tools, in order to understand the underlying motivations of their choices in terms of tools awareness. Also, the study wants to assess whether – and to what extent – designers rely on these biomimicry tools within the NPD process.

To this end, new indicators are built mainly to measure the tools awareness which is based on the distance between how the existing literature assesses these tools and the perception of our surveyed respondents. An exact logistic regression model has been then implemented in order to assess the impact of biomimicry tools on the probability to generate innovative outcomes in the NPD process.

The paper unfolds as follows: after providing the reader with a comprehensive background clarifying the origins and meanings of biomimicry, we describe the main biomimicry tools and seek to identify traces of their uses in the NPD process. Then, a methodological section is instrumental to explain how we designed the survey, selected the sample and collected data. The results section follows showing the main findings, providing descriptive statistics and assessing the impact of tools awareness on the NPD process. We sum up our main insights and implications followed by some main limitations and recommendations for future research.

Background

Bionics, Biomimetics, Biomimicry and Bio-Inspired Design

In the literature, researchers often use biomimicry, bionics, biomimetics, and bio-inspired design as synonymous. Although the general meaning of these words may seem similar, they still have small – but significant – differences.

The first formal definition dates back to 1958 when Steele (1924-2009) defined **bionics** as: “imitation of nature, natural processes, and living organisms in the design of mechanical systems – as solutions ‘to engineering problems’” (Papanek, 1984). Vogel (1998, p. 250) defined bionics as follows: “…as based on living systems. The word ‘systems’ came naturally to those, mostly engineers, initially involved; neural systems and physiological controls formed biological parallels to human technology’s cybernetics and systems theory”.

The word **biomimetics** was publically used for the first time in the Webster dictionary in 1974: “The study of the formation, structure, or function of biologically produced substances and materials (as enzymes or silk) and biological mechanisms and processes (as protein synthesis or photosynthesis) especially for the purpose of synthesizing similar products by artificial mechanisms which mimic natural ones” (Harkness 2002, p. 481).

According to this definition, in 1994, Janine Beynus, a natural science writer, coined the word **biomimicry**. She gave a definition of biomimicry from three points of view (Benyus, 1997, front matter):

- “*Nature as model*. Biomimicry is a new science that studies nature’s models and then imitates or takes inspiration from these designs and processes to solve human problems.
- *Nature as measure*. Biomimicry uses an ecological standard to judge the “rightness” of our innovations. After 3.8 billion years of evolution, nature has

learned: What works. What is appropriate. What lasts.

- *Nature as mentor*. Biomimicry is a new way of viewing and valuing nature. It introduces an era based not on what we can extract from the natural world, but on what we can learn from it."

The last term that we will discuss is **bio-inspired design**, mostly used in the engineering field. Bras, Professor of Engineering at Georgia Institute of Technology, argues that biomimicry implies copying, and simply copying is not necessarily the best or smartest way to do things. He also says that inspiration allows the engineer to take the best from nature and put it in a new (engineering) context (Crawford, 2012).

Biomimicry in the Literature: Identifying the Key Contributions

A number of existing studies focus on the adoption, adaptation and use of decision-making and creativity tools with the aim, for instance, to deal with the Fuzzy Front End of innovation (Achiche et al., 2013), rather than supporting managers in measuring NPD success factors (Bhuiyan, 2011); some scholars provide a cross-industry overview of tools adoption (Nijssen and Frambach, 2000). However, the literature is still silent on the adoption and use of biomimicry tools by companies.

In order to fill this gap, we started investigating academic contributions using Scopus, Web of Science, and Google Scholar. The article selection was performed using the following keywords: "biomimicry", "biomimetics", "bio-inspired design", "bionics", "product inspired by nature". This search routine resulted in a pool of 114 articles. Reading their abstracts and conclusions allowed us to select only the articles that exclusively analyzed tools[1], and in particular biomimicry tools, which are the sole focus of this paper.

Biomimicry Tools in the NPD Process

In the literature, we found many methodologies that apply Biomimicry in the NPD process. We follow the description of the NPD process that Helms and co-authors (2009) propose:

- (Phase 1) problem definition;
- (Phase 2) problem reframing;
- (Phase 3) biological solution search;
- (Phase 4) biological solution definition;
- (Phase 5) principle extraction;
- (Phase 6) principle application.

The pattern of problem-driven biologically-inspired design follows a progression of these steps which, in practice, is non-linear and dynamic in the sense that output from later stages frequently influences previous stages, providing iterative feedback and refinement loops. During the process, many tools can be used as support; we focus our attention on the 7 biomimicry tools listed above and try, according to their characteristics, to position them along these steps (see Table 1):

Table 1. Biomimicry tools in NPD process steps

Tool[2]	Description	Steps

[1] See Supplementary Material n.1 for a complete list of the references.

AskNature	Web-based search engine for natural phenomena.	• Problem reframing; • Biological solution search.
IdeaInspire	Software-based search and retrieval of both natural and artificial systems and strategies, founded on SAPPhiRE model (VNA) and/or functional modeling.	• Biological solution search; • Biological solution definition.
Engineering-to biology thesaurus	Translation of engineering to biology at a functional level and methodology to employ the thesaurus in the design process.	• Principle extraction
DANE	Database for searching and authoring SBF (Structure-Behavior-Function) design cases/models.	• Problem reframing; • Biological solution search.
BioTRIZ	This tool supports designers in dealing with the contradictory perspectives coming from the natural world.	• Problem reframing
Knowledge-based CAD system	These tools help engineers design objects described by the SBF or SAPPhIRE models.	• Principle application
BioCards	Tools used to communicate design principles found in nature.	• Principle extraction; • Principle application.

Methodology

Survey Design

To retrieve information from companies using biomimicry tools, we launched a survey on Limesurvey[3], which is an online portal[4]. With the help of two statisticians, as a pre-test, we submitted the survey to a sample of five researchers to check the duration and clarity of the questions. By doing so, we found out local optima in terms of survey length and quantity-quality of information retrieved. In order to maximize the quality of information, the survey was complemented with face-to-face interviews.

[2] See Supplementary Material n.2 for a comprehensive description of their characteristics.

[3] https://www.limesurvey.org/en/

[4] See Supplementary Material n.3 for the full questionnaire.

Sample Selection

The goal of this research was to retrieve information from biomimicry practitioners. Hence, our target was composed of designers. Afterwards, we extended the sample to include researchers with at least two years of experience in biomimicry projects as they could also be a valuable source of information.

To get companies involved we used social networks and contacted the key informants. In particular, we used LinkedIn and Facebook to select individuals from groups specialized in Biomimicry. We first tried to reach people using posts on the groups and then contacted them individually with private messages in order to obtain a higher response rate. We sent about 500 requests resulting in 102 answers of which 52 are incomplete responses and 50 provided full answers. Out of the 50 who provided full responses, 13 were answered by practitioners with less than 1 year of experience with issues related to the NPD process and were consequently not considered in our analyses. Hence, the final sample, retrieved from the 37 complete questionnaires, is composed solely of experienced researchers and designers in the NPD process but also in dealing with biomimicry.

Table 2 shows the distribution of the respondents' roles by levels of experience:

Table 2. Roles by experience levels

Experience level	Researchers	Designers	Both
None	35.7%	43.7%	5.0%
Less than 2 years	21.4%	12.5%	0.0%
2-5 years	0.0%	18.7%	15.0%
5-10 years	21.4%	12.5%	20.0%
More than 10 years	21.4%	12.5%	60.0%

The most experienced practitioners in our sample are professionals dealing with both research and design activities. By comparison, respectively 35.7% and 43.7% of researchers and designers have no practical experience in the biomimetic field. Furthermore, 44% of designers and researchers work in small companies; 9% work in large firms with more than 1,000 employees as well (see Table 3).

Table 3. Distribution of respondents in companies

Number of employees	Answers	Percentage
Less than 10	21	44.0%
11-49	2	4.0%
50-249	3	6.0%
250-499	0	0.0%
500-999	2	4.0%
More than 1000	9	18.0%

Data Collection

The survey consisted of 46 questions divided into six sections (see Supplementary Material for the full questionnaire) assessed on a five-point Likert scale. To retrieve more information we performed a follow-up face-to-face interview with a Quebec-based company using biomimicry. The company specializes in 'Personal Equipment and a Cutting-Edge Research & Development (R&D) Services.' We interviewed the President of the company, a Human Factors and Ergonomics specialist with eighteen years of experience in NPD within the industry. We enquired about their NPD process integrated with biomimicry, the kinds of tools used as a support, comparison between traditional and biomimicry NPD processes, and storytelling about some past and current projects.

Results

Familiarity with Biomimicry Tools

Figure 1 shows the levels of familiarity of designers and researchers with the tools proposed. The most known tool is AskNature with its taxonomy (Avg = 3.97); BioTRIZ and BioCards follow with an average rate higher than 2; the others are not very popular.

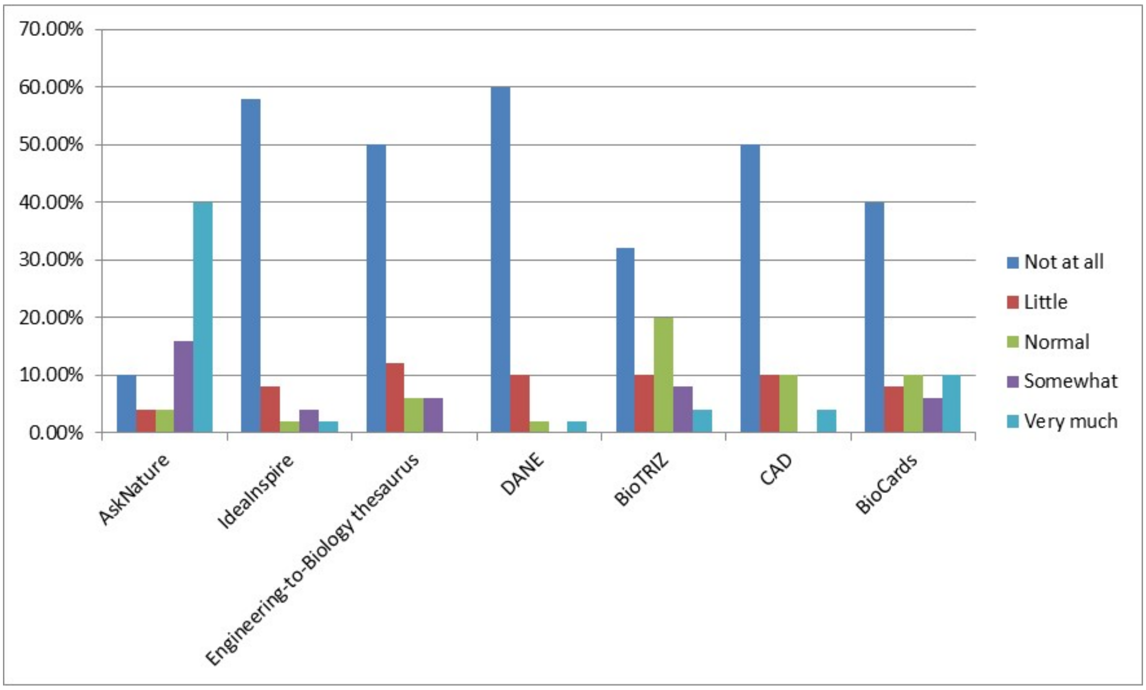

Figure 1. Level of familiarity with biomimicry tools

This was also confirmed in our interview in which the President stated that they do not use any biomimicry tools during the NPD process. They prefer exploring the nature to observe and take inspiration directly from it, or to use their knowledge to solve problems and create new products. He also added that biomimicry is generally used along with traditional tools, but to take advantage of these approaches, researchers and designers need to be skilled in both industrial processes and natural processes as nature produces multiple solutions to each problem.

We then analyzed the answers related to the three most known tools (those with Avg ≥ 2) provided in Figures 2 to 4.

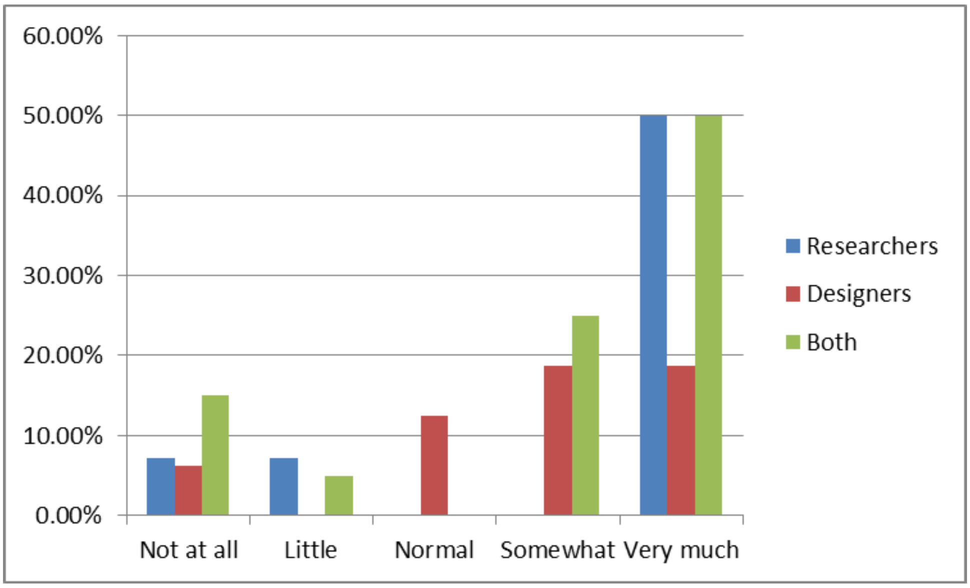

Figure 2. Familiarity with AskNature

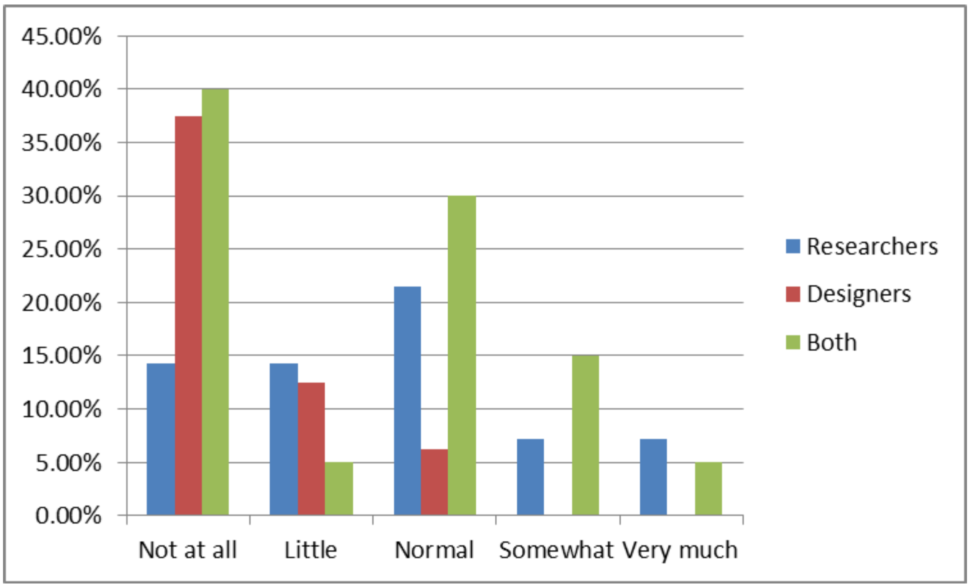

Figure 3. Familiarity with BioTRIZ

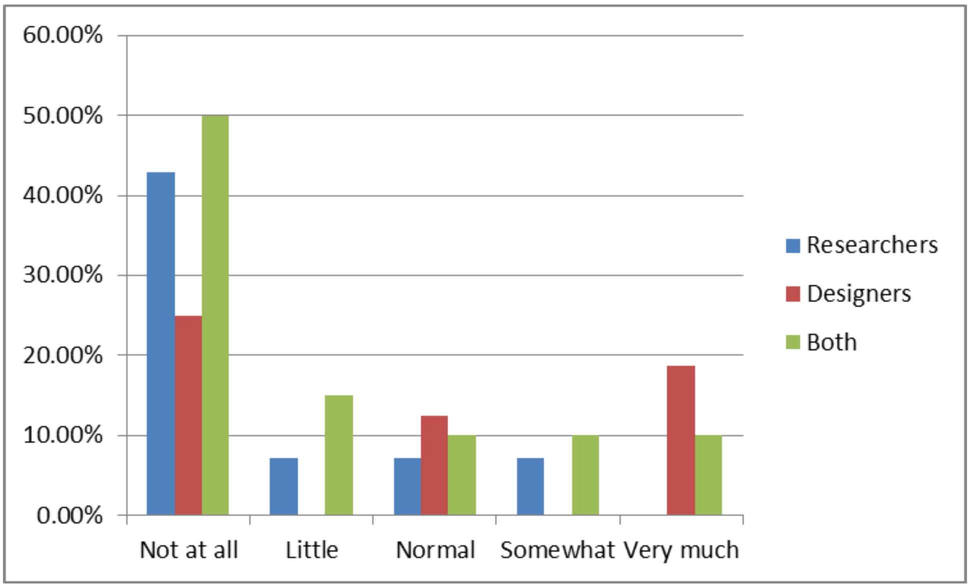

Figure 4. Familiarity with BioCards

Figure 2 shows that respondents having experience both with research and design, and pure researchers as well, show the highest level of familiarity with AskNature. Designers moderately know this tool. An opposite picture holds for BioTRIZ (Figure 3), with designers having almost no knowledge of it. Finally, Figure 4 shows that although the majority of the respondents are not familiar with BioCards, almost 20% of designers have in-depth knowledge of its characteristics.

Biomimicry Tools in NPD Phases

Phases 1 and 2: Problem Definition and Reframing

Going through Phase 1 and Phase 2 is a necessary condition to formulate a specific problem and find the functions that better solve it. Figure 5 shows which tools are used by designers and researchers during these phases. The sum of the percentages is more than 100%; this means that some respondents use more than one tool in these phases. It emerges that beyond using AskNature, respondents prefer to go for other solutions (e.g., outsourcing).

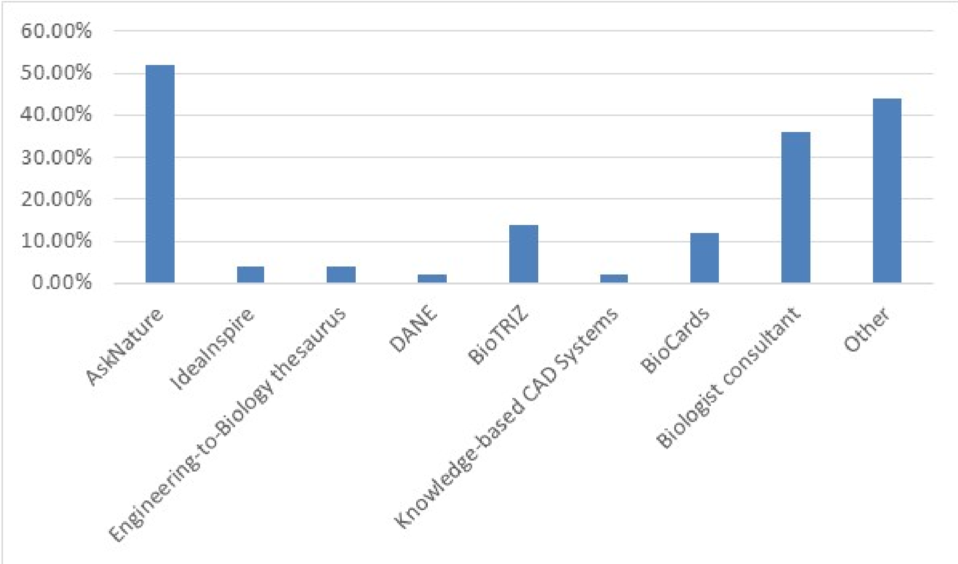

Figure 5. Tools usage in Phases 1 and 2

The most used tool in these phases is AskNature; this tool can inspire, suggest and link functions to the natural phenomena that best perform them. It is worth noting that 44% of the respondents used other tools not related to biomimicry. In fact, these phases are still in the company domain and are simply the translation of the problem into the functional language. In 36% of cases, these phases are outsourced to biology consultants. Among the other tools used we find Google searches, scientific journals, direct contact with nature, self-built tools, and conversations with clients.

Phases 3 and 4: Biological Solution Search and Definition

During these phases, designers and researchers have to find a natural phenomenon that better performs the functions previously identified and framed. Figure 6 shows the tools used in these two phases:

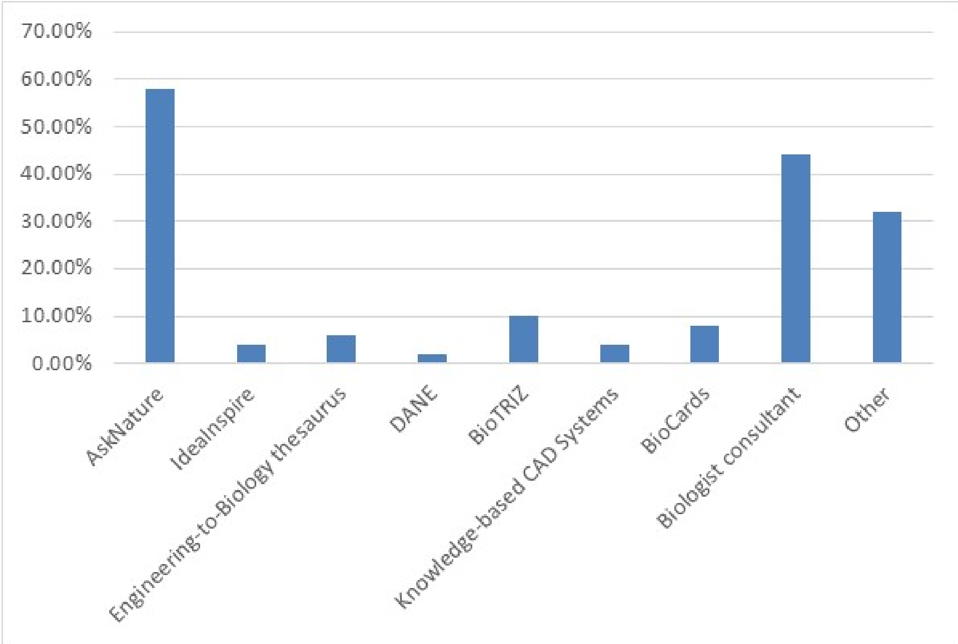

Figure 6. Tools usage in Phases 3 and 4

As expected from Figures 5 and 6, the most used tool is still AskNature. Its large utilization is justified by the fact that it is a flexible tool, being used in many phases. If 52% of the respondents used it in the problem definition and reframing phases, it can be anticipated that at least this percentage of respondents used it in the following phases because the tool is useful in all the four phases. Biology consultants are still widely used and this could signal a lack of professional biological knowledge from respondents. Other tools are scientific journals, Google searches and direct contact with nature.

Phase 5: Principle Extraction

Once chosen, researchers and designers have to analyze and translate the natural phenomena from the natural domain to the engineering field.

Figure 7 highlights that 35% of the respondents outsource this phase using a biology consultant. We can say that this is the most complex and risky phase of the process, and as such it is comprehensible that companies want to outsource the phase relying on experts in order to solve the problem.

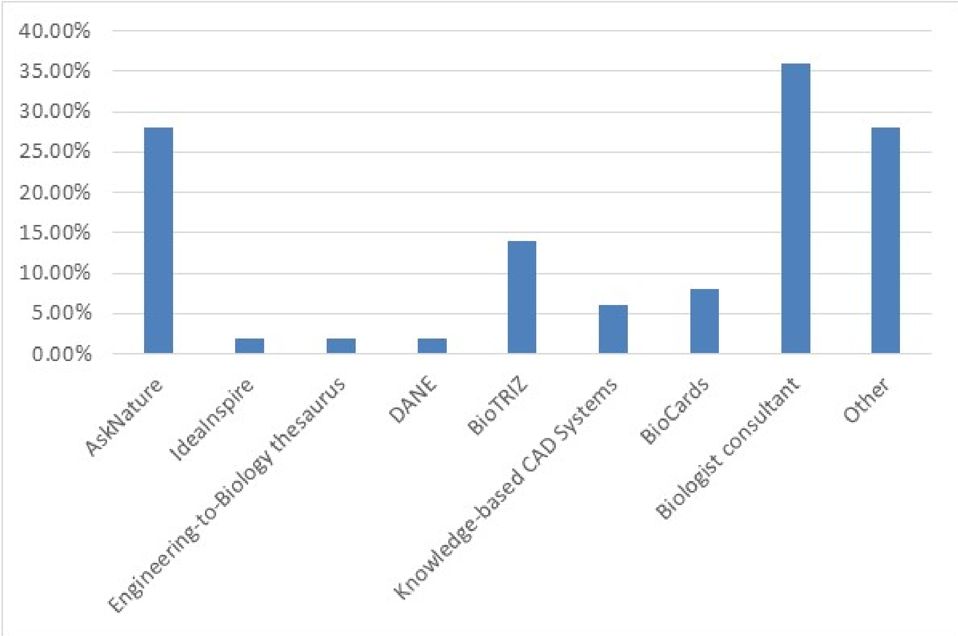

Figure 7. Tools usage in Phase 5

Regarding the other tools, the most used is still AskNature, even though 15% of respondents use BioTRIZ, which is a complex – but very useful– tool, especially in this phase. Among other tools, generic Web searches and scientific journals were also identified in the survey. The following remark given by one of the respondents better clarifies and explains these trends:

> "I believe that if you are going to appropriately and successfully translate a biological solution you have to gain a deep understanding of it. Thus, I feel significant frustration at "fluffy" methods that try to take shortcuts. For the same reasons, I also believe those same methods lead people to not have deep conversations that technologists must have around a design and its requirements to be successful. The biomimicry process – and most of the associated design movement – totally falls down when it comes to helping people make that transition from inspiration to implementation."

Phase 6: Principle Application

The last step is the application of principles and generation of new ideas, where researchers and designers have to create concepts that can solve the original problem. AskNature remains the most used tool. Other tools indicated by our respondents are brainstorming and focus groups, which are standard tools categorized under "other" in Figure 8.

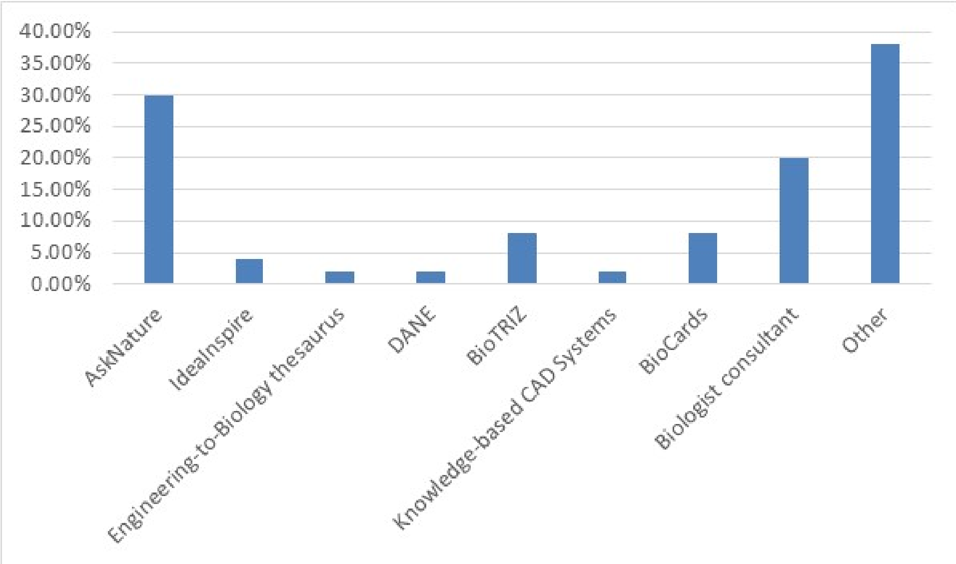

Figure 8. Tools usage in Phase 6

Biomimicry Tools Assessment

In order to assess biomimicry tools, we decided to rely on five indicators. According to Fu and co-authors (2014), the first three are cognitive factors, whilst the remaining ones are implementation factors:

- Modality of representation: form that an example or (analogical) stimulus might take on, corresponding to the variety of sensory perceptions that might be involved in processing them;
- Expertise: the level of experience, training, and knowledge that a designer has with respect to use the tool;
- Analogical reasoning: the cognitive steps and characteristics humans employ when working to find, retrieve, translate, abstract, transfer, and evaluate information or mapping knowledge from a source application to a target application;
- Accessibility: how available the tool or method is to the academic or public community for its use in a design practice;

- Automation: how automated the solving of the design problem is using the tool/method, or how much human input/work is required to reach a result.

Table 4 sums up results from the survey.

Table 4. Tools assessment (in brackets, assessment from the literature e.g., Fu et al., 2014)

Tools Assessment					
Indicator / Tool	**Modality of representation**	**Expertise**	**Analogical reasoning**	**Accessibility**	**Automation**
AskNature	3.65 (5.00)	3.86 (4.00)	3.73 (1.00)	4.30 (5.00)	2.77 (3.00)
IdeaInspire	4.00 (5.00)	3.80 (4.00)	4.20 (1.00)	4.40 (5.00)	3.50 (3.00)
Engineering-to-Biology thesaurus	2.71 (2.00)	3.25 (3.00)	3.13 (1.00)	3.11 (5.00)	2.00 (1.00)
DANE	4.00 (3.00)	4.00 (2.00)	3.50 (1.00)	3.00 (5.00)	4.00 (1.00)
BioTRIZ	3.63 (2.00)	3.38 (2.00)	3.82 (1.00)	2.69 (5.00)	3.33 (1.00)
Knowledge-based CAD Systems	3.83 (n/a)	3.43 (n/a)	3.50 (n/a.)	2.62 (n/a)	3.60 (n/a)
BioCards	4.17 (n/a)	3.50 (n/a)	3.78 (n/a)	4.12 (n/a)	3.00 (n/a)
Cronbach's α	*0.792*	*0.732*	*0.711*	*0.664*	*0.690*
Avg. Int. Corr.	*0.433*	*0.353*	*0.330*	*0.284*	*0.308*

These results allow us to answer the first research question: *Do designers and researchers know how to use biomimetic tools?* By comparing the results of the survey with those presented in recent academic contributions, we still see that AskNature is the most known biomimicry tool and the evaluation given by our interview corresponds to the evaluation given in the literature, except for one indicator that corresponds to analogical reasoning. A tentative explanation of this result may be the fact that AskNature tends to be used as a search engine similar to a Web keyword search without stimulating analogical reasoning; instead, our study reveals that designers and researchers take advantage of the taxonomy as it helps to create and connect apparently distant bits of knowledge.

In order to provide a robust answer to the research question, an awareness indicator was created. The need for awareness indicators when using NPD tools has been already debated in the literature (Nijssen and Frambach, 2000; Appio et al., 2011). Our indicator is based on the distance (Equation 1) between the two assessments for each indicator for each tool:

$$D_{rjk} = |AL - AS|_{rjk} \; \forall \; r=1, \ldots, 50; j=1, \ldots, 5; k=1, \ldots, 5 \qquad (1)$$

where *D* is the distance, *AL* is the assessment from the literature, *AS* represents the assessment from the survey, *r* identifies the respondent, *j* describes the tool, and *k* represents the specific indicator. We calculated the absolute value because we are interested in the error made by the respondent in assessing the tool. Calculating the mean value for each indicator of each tool, we get the following results (Table 5):

Table 5. Tools distances

	Distances				
Tool / Indicator	AskNature	IdeaInspire	Eng.-to-Biology thesaurus	DANE	BioTRIZ
Modality of representation	3.00	4.46	4.38	4.89	4.27
Expertise	1.65	4.40	4.19	4.92	3.78
Analogical reasoning	2.22	4.76	4.38	4.86	3.92
Accessibility	1.86	4.70	4.24	4.92	4.05
Automation	2.59	4.57	4.24	4.94	4.22

We observe that all the tools (except AskNature) show high distance values. Basically, this result may have two interpretations:

- Designers and researchers do not use these tools so they cannot provide an accurate assessment. A missing value or the answer “I don’t know” in the survey corresponds to a value of 5 in the correspondent "Distance". This is because the information asymmetry has the highest value in this case;

- Designers and researchers try to use the tools without knowing them well, so they cannot perceive their real value.

In both cases, many biomimicry tools used in the NPD process seem not to be understood by our respondents.

As a second step, we calculated the "Awareness Indicator" which is useful to better analyze the results obtained previously. The indicator (Equation 2) is calculated using the distances obtained in the first step:

$$A_{rj} = 1 - \frac{\sum_{k=1}^{5} \mathrm{Drj}}{25} \times 100 \quad \forall\ r=1, \ldots, 50; j=1, \ldots, 5 \qquad (2)$$

where *r* identifies the respondent, *j* describes the tool, and *k* represents the specific indicator. Table 6 shows the results of the awareness indicator where 0% means no awareness at all and 100% would mean full awareness:

Table 6. Awareness indicators for biomimicry tools

Awareness Indicator on	Mean value	Std. deviation
AskNature	0.545	0.039
IdeaInspire	0.084	0.033
Engineering-to-Biology thesaurus	0.143	0.042
DANE	0.018	0.015
BioTRIZ	0.190	0.043

As we expected, the highest value is represented by AskNature even though it is only 54%: by considering a subject that can perfectly use AskNature having an awareness indicator of 100%, we may say that researchers and designers in this case are using the tool they master at 55% only.

Biomimicry Tools and NPD Performance

In this section we provide an answer to the third research question: *Do biomimicry tools have an impact on the NPD process?* To do so, we associate the tools awareness to the probability of generating innovative ideas using standard regression techniques. As AskNature is the biomimicry tool which designers and researchers are most aware of, we will focus our analyses on this specific tool. A binary variable 'innovativeness' is created, where:

- *Innovativeness*=1, if the number of ideas generated is ≥ 4 (measured on a five-points Likert scale),
- *Innovativeness*=0, otherwise.

The rationale behind this choice is that the greater the number of ideas being recombined, the greater the odds of generating original solutions to push forward into the NPD process (Gruber et al., 2013). A number of control variables have been introduced, namely, the time needed to go from the first to the last step of the NPD process; the size of the organization; and if the core activity had been R&D, production, or a balanced configuration. The model is as follows (Equation 3):

$$Pr(\text{Innovativeness}=1 \,|\, \text{Awareness}_{\text{AskNature}}, \text{Controls})=\beta_0+\beta_1 * \text{A}_{\text{rAskNature}}+\beta_k * \text{Controls} \quad (3)$$

with k=1, …, 3 identifying the three control variables.

An exact logistic regression was used to model the binary outcome variable in which the logarithm of its odds is modeled as a linear combination of the predictor variables (Hosmer et al., 2013). The estimates given by exact logistic regression do not depend on asymptotic results. Results are shown in Table 7:

Table 7. Exact logistic regression results

Variables	Model (A)	Model (B)	Model (C)	Model (D)
Awareness AskNature	2.869*	4.059**	3.052**	3.276**
	(1.494)	(1.900)	(1.536)	(1.614)
Time		-1.088**		
		(0.487)		
Size			-0.249	
			(0.169)	
Activity				0.234
				(0.290)
Model score (χ^2)	3.97	9.42	6.04	4.59
Pr >= score	0.046	0.006	0.045	0.098
N	37	37	37	37

Standard errors in parentheses
* p<0.1 ** p<0.05 *** p<0.001

The tests in the overall models are chi-square tests and are statistically significant. In all the models considered, using AskNature may potentially increase the chances to get more innovative ideas, making the NPD process more effective. Preliminary signals of this fact already emerged in the correlation table (see Appendix). This relationship also holds when we introduce the control variables.

The power of this tool resides in the fact that developers make an effort to translate biological information so it would be accessible to non-biologists, and to serve as a source of inspiration for biomimetic design (Deldin and Schuhknecht, 2014). In addition, AskNature is a free tool and it is organized in such a way that the gap between biology and fields such as engineering, architecture, industrial design, chemistry, organizational development, is reduced. Shortening the distance between these fields works in favor of an easier knowledge recombination (Leiponen and Helfat, 2010), potentially at two levels: scientific and technological. This recombination is almost always at the basis of firms' innovativeness.

The other advantage is that it represents a place where key informants can freely interact to generate their solutions. In this way, AskNature is enacting a kind of Virtual

Community of Practice (VCoP) allowing both experts and non-experts to try to find original solutions, and enacting a collective learning movement (Sawhney et al., 2005). But this was already in the spirit of its originator, Benyus when she wrote the Biomimicry manifesto in 1997.

Interestingly, controlling for time (Model B), one may conclude that undertaking longer NPD processes may have a negative impact on the probability of generation of new ideas; in such a context, using a biomimicry tool such as AskNature may increase fourfold the chances to get innovative ideas. Potentially, the higher the number of ideas being recombined, the smaller the time to come up with an original solution.

Conclusion and Implications

Unveiling how researchers and designers are framing biomimicry in the NPD process may provide both scholars and practitioners with new lenses through which to look at the ways they conceive and make new products and services (Ulhøi, 2015). Among the many challenges this scenario poses, understanding whether researchers and designers are aware of the biomimicry tools (Fu et al., 2014) and to what extent such tools are effective to improve the NPD performance are key.

To address this twofold aim, we implemented a systematic procedure: first, an in-depth literature review was performed in order to make sense of which biomimicry tools are at the core of the innovation discourse. We selected the most important biomimicry tools and then surveyed a number of firms from which we retrieved useful information on the use and awareness of these biomimicry tools. Then, a face-to-face semi-structured interview was carried out with one of the companies implementing biomimicry tools in its NPD process. Other relevant information emerged which complemented that collected through the survey. An awareness indicator was created contrasting the distance between the scores provided by the literature and ours emerging from the field; then, an exact logistic regression model was estimated. Some important – though preliminary –conclusions emerge.

First, researchers and designers are not familiar with biomimicry tools. They only state to know AskNature, even though they underestimate the potential of its peculiar characteristics. Considering their awareness, this tool performs better than the others in terms of the way of representing concepts, the proper match it makes between its characteristics and the level of experience required by the researchers and designers, the cognitive steps it entails in order to map the universe of possible analogies, its accessibility via a user-friendly Web interface, and finally the automated routines it deploys facilitating the transformation of the human input in the generation of solutions to design problems. Also, when we assess the distance between the surveyed respondents' assessment and the scores presented in the literature, things do not substantially change: AskNature is the biomimicry tool which researchers and designers are more aware of. The interview was extremely revealing in that respect: researchers and designers sometimes say they are using biomimicry tools but what they are actually doing is readapting some shapes to their products. According to the company we interviewed, nature should be investigated directly without the filter of tools and applied alongside traditional tools.

Second, very few biomimicry tools are used along the phases of the NPD process; very often, companies prefer to outsource specific phases of the process to biology consultants because they do not know yet how to cope with this complexity. Third, biomimicry tools like AskNature may contribute to increasing the chances to generate more innovative ideas. We considered AskNature and noticed that using this biomimicry tool would allow companies to increase fourfold their chances of coming up with innovative ideas. This is true regardless of the size of the organization, the speed of the NPD process phases, and the type of core activity the organization is carrying out. Although not generalizable, our results can stimulate practitioners to deepen their knowledge about other tools and try to adapt them to their own contexts.

Important implications for practitioners therefore deserve attention. First and foremost, top management and designers should engage in fruitful conversations in order to understand how their traditional way of generating ideas in the NPD process may be readapted and improved by using biomimicry tools. In fact, as our preliminary results show, as soon as the level of awareness about biomimicry tools is raised, and a consistent application follows, NPD performance improves. Raising awareness may be done for instance through specific training sessions.

Second, learning how to use these tools may contribute to lowering the costs of relying on external experts (e.g., biology consultants); indeed, outsourcing key phases of the NPD process may result in an increase of both monetary and coordination costs. It goes without saying that the probability of unintended spillovers is higher when you interact with external sources.

Third, and as a consequence of the former point, top management should consider the opportunity to build interdisciplinary teams where both engineers and biologists can interact and find innovative solutions. This is because of the recombination mechanisms operating at the interface of two diverse sources. Finally, biomimicry tools have the potential to accelerate the NPD process as they have systematic ways of excluding useless alternatives. This would allow designers to reach the optimal solution quickly and in a systematic way.

Limitations and Future Research

This research has limitations. First, as the field of investigation is relatively new, the aim of the research is exploratory; accordingly, the sample may not be considered representative of the design population. Future researchers may extend the survey worldwide by allowing for cross-country and industry comparisons. Second, trying to relate the background of designers to their tools' awareness may unveil the significant results; perhaps, a good way of raising both familiarity and awareness is introducing specific teaching modules on how to adopt and adapt biomimicry tools within NPD processes. Third, the interaction of biomimicry with other, more traditional tools is not investigated and the combining effect of their impact on NPD performance may provide important insights. Finally, we provide a proxy for measuring the NPD outcome that only takes into account the quantity of ideas generated; it would be interesting to disentangle the effect of awareness of biomimicry tools on the quality of ideas generated. A good starting point may be distinguishing between incremental and radical ideas, or looking at how many of these ideas – due to their novel and original content – are worthy of patent protection or not.

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Appendix. Descriptive statistics and Pearson's correlations

	Innovativeness	**Awareness AskNature**	**Time**	**Size**	**Activity**
Innovativeness	1.000				
Awareness AskNature	.3320**	1.000			
Time	-.3676**	.0626	1.000		
Size	-.2121	.0817	.1012	1.000	
Activity	.0374	-.2677	.2658	.2491	1.000
Mean	.5946	.5460	3.729	2.649	2.324
Std, Dev.	.4977	.2402	1.071	2.176	1.292
Range	0-1	.16-.84	2-5	1-6	1-4

* p<0.1 ** p<0.05 *** p<0.001