Is Biologically Inspired Design Domain Independent?

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Abstract: Current theories of biologically inspired design assume that the design processes are domain independent. But is this assumption true? Design Study Library (DSL) is a digital library of eighty-three cases of biologically inspired design collected from a senior-level interdisciplinary class at Georgia Tech over 2006-2013. We describe a preliminary analysis of the DSL case studies. We posit that the assumption about the domain independence is questionable. In particular, some of the parameters in the domains of physiology and sensing appear to be different from the more common domains of mechanics and materials.

Background, Motivation and Goals

The paradigm of biologically inspired design espouses the use of biological systems as analogues for inspiring the design of technological systems as well as standards for evaluating technology designs (Bar-Cohen 2011; Benyus 1997; Bhushan 2009; French 1994; Gleich et al. 2010; Turner 2007; Vincent & Mann 2002; Vogel 2000). Although nature has inspired many a designer in history, including Sushruta, Leonardo da Vinci, and the Wright brothers, over the last generation the paradigm has evolved into a design movement. This transformation is pushed by the perennial desire for design creativity and pulled by the growing need for environmentally sustainable designs. The revolution is manifested through an exponentially expanding literature including both patents (Bonser & Vincent 2007) and publications (Lepora et al. 2013).

However, our understanding of the processes of biologically inspired design remains modest. It is noteworthy that biological phenomena occur at scales ranging from nanometers to megameters, and from nanoseconds to gigaannums. Similarly, biological phenomena occur in a variety of domains ranging from bacteria to archaea to eukaryotes. However, all extant theories of biologically inspired design appear to assume that the design processes are domain- as well as scale-independent (e.g., Goel, McAdams & Stone 2014). Pedagogical techniques for teaching biologically inspired design and computational tools for supporting its practice also make the same assumption. But is this assumption true?

This raises another issue: what is a domain? To be specific, let us consider Weiler & Goel's (2015) description of a mechanical device for harvesting water inspired in part by the design of mitochondria. The issue of scale in this example seems clear; there are two scales of interest: (i) the scale of mitochondria (micrometer) and (ii) the scale of the mechanical device (meter). Thus, apparently there are two scales of interest in biologically inspired design: the scale of the biological source case and the scale of the target design problem.

Similarly we might say that in biologically inspired design, there are two domains of interest: the domain of the source biological phenomenon (mitochondria in this example) and the domain of the target design problem (mechanical devices). To be precise, we adopt a characterization of a domain from the artificial intelligence literature on design (Chandrasekaran 1990; Chandrasekaran, Josephson & Benjamins 1999; Dym & Brown 2012; Goel 1997): a domain is characterized by the kinds of objects, relations and processes that occur in it. Further, given the context of cross-domain analogical transfer in biologically inspired design (Goel 1997, 2013; Goel, McAdams & Stone 2015; Shu et al 2011), we view the real domain of interest to be the "bridging domain" between biology and design. Thus, in the example of the mechanical device, the domain of interest is water harvesting that occurs in biological as well as technological systems (and not mitochondria or mechanical devices).

The Design Study Library (DSL for short) is a digital library of eighty-three case studies of biologically inspired design (Goel et al. 2015). The case studies were collected over 2006-2013 from extended collaborative projects in a senior-level interdisciplinary class at Georgia Institute of Technology. These case studies provide an empirical basis for examining the domain independence of biologically inspired design. In this paper, we describe a preliminary analysis of the eighty-three case studies. We posit that the assumption about the domain-independence of biologically inspired design is questionable.

Section 2: Biologically Inspired Design

The growth of biologically inspired design movement has lead to a proliferation of information-processing theories, pedagogical techniques, and computational tools supporting its practice.

2.1 Information-Processing Theories: Some information-processing theories of biologically inspired design are descriptive: Design Spiral (Baumeister et al. 2012), for example, derives from observations of biologically inspired design in practice; Shu et al. (2011) provide an alternative descriptive account. Some theories are normative: BioTRIZ (Vincent et al. 2006), for example, applies the well-known TRIZ design methodology (Altshuller 1984) to biologically inspired design; Nagle & Stone (2010) provide an alternative method. Some theories are explanatory: Chakrabarti's and his colleagues' GEMS model (Srinivasan & Chakrabarti's 2011) and Goel's (2013a) Task Model seek to provide explanations of observed biologically inspired design practices. *All* these descriptive, normative and explanatory theories of biologically inspired design are domain-independent as well as scale-independent.

2.2. Pedagogical Techniques: Several educational programs offer opportunities for learning about biologically inspired design. For example, Arizona State University offers a variety of courses on biomimicry for professional and student designers (http://biomimicry.asu.edu/), and Georgia Tech offers a sequence of undergraduate courses that leads to a certificate in biologically inspired design (http://www.cbid.gatech.edu/). Arizona State University's courses generally use the Design Spiral (Baumeister et al. 2012) as the design methodology. Goel's (2013a) Task Model both derives from cognitive analyses of design practices in the Georgia Tech ME/ISyE/MSE/PTFe/BIOL 4740 course on biologically inspired design, and has influenced the teaching in the class (Yen et al. 2011, 2014). *All* these pedagogical techniques are domain-independent as well as scale- independent.

2.3. Computational Tools: Many computational tools are available for supporting biologically inspired design. The Biomimicry Institute's AskNature provides access to a functionally indexed digital library of textual and visual descriptions of biological systems (http://www.asknature.org/; Deldin & Schuknecht 2014). IDEA-INSPIRE (Chakrabarti et al. 2005) and DANE (http://dilab.cc.gatech.edu/dane/; Goel et al. 2012) provide access to functionally indexed digital libraries of multimodal structured representations of biological and technological systems. Vincent and colleagues (2006) are developing BioTRIZ, a biomimetic version of the famous TRIZ system for supporting engineering design (Altshuller 1984). Nagle (2014) has developed a thesaurus for functions in biologically inspired design. Watson+ (Goel et al. 2015) builds on IBM's Watson cognitive system and acts as a research assistant for biologically inspired design. *All* these computational tools are domain-independent as well as scale-independent.

Section 3: The Design Study Library

The Design Study Library (DSL) is a web-based, interactive, digital library of eighty three case studies of biologically inspired design (Goel et al. 2015). Each case study in DSL consists of one or more documents describing a design project, and is indexed by *Function,* *Structure, Domain Principle* and *Operating Environment*. DSL supports multiple methods for users to access these documents.

All eighty-three case studies in DSL come from open-ended extended collaborative design projects from 2006 through 2013 in the Georgia Tech ME/ISyE/MSE/PTFe/BIOL 4740 class. This is a yearly, interdisciplinary, project-based class taken mostly by senior level students. During 2006-2013, the class was co-taught jointly by biology, engineering, and design faculty led by Professor Jeannette Yen. During these years, the classes were composed of students from a variety of other science and engineering disciplines. The precise composition of the class varied from year to year, but in general the class consisted of a majority of engineers.

In the Georgia Tech ME/ISyE/MSE/PTFe/BIOL 4740 class, students work in teams of 4-5 on extended, open-ended, self-selected design projects. Instructors ensure that each team has at least one student majoring in biology and a few from different engineering and design disciplines. Each team develops a conceptual design that can address a technical problem based on one or more biological analogues. Each team has one or more faculty mentors. Yen et al. (2011) discuss the challenges in teaching the class; Yen et al. (2014) trace the evolution of the class from 2006 through 2012.

Section 4: Prior Analysis of DSL

Prior analysis of the case studies in DSL pertained to the relationship between biologically inspired design and environmental sustainability. Goel et al. (2015) found that environmental sustainability was an explicit goal of about one fourth of the case studies. They also found that in some case studies, although sustainability was not a design goal, the designers' analyses indicated that the design would be more sustainable than conventional designs. They found this kind of *serendipitous sustainability* in about 8% of the case studies. Taking serendipitous sustainability into account, sustainability was a factor in about a third of the case studies.

Section 5: Categorization of the Case Studies

Our analysis makes use of a dozen categories for classifying the case studies in DSL in addition to Function, Structure, Principle, and Operating Environment that apply to all eighty three case studies. First, as noted above, the DSL case studies were classified and labeled as "intentionally sustainable" or "serendipitously sustainable". Second, cases that contained "environmental impact analysis" were tagged as such. Third, five labels were obtained from Goel's (2013a) Task Model of biologically inspired design: *problem decomposition, compound analogy, problem reformulation, problem-driven design,* and *solution-based design*.

Finally, four labels for classifying domains were obtained from Professor Yen, a Georgia Tech Professor of Biology and the primary instructor of the Georgia Tech ME/ISyE/MSE/PTFe/BIOL 4740 course: *physiology, mechanics, materials*, and *sensing*. While the domains of mechanics, materials, and sensing are straightforward, real domain of interest in case of "physiology" is the mechanism of the functioning of a system that can be instantiated in both physiology and technology. Table 1 provides brief characterizations of the twelve categories including the four domains.

A preliminary analysis revealed that nine case studies in DSL were too short or vague to be tagged with consistency, and thus were deleted from further analysis. The remaining seventy four case studies were categorized independently by two of the coauthors (Tuchez and Hancock). Both are computer scientists familiar with biologically inspired design. The two coders initially labeled the case studies independently, then negotiated about the precise characterizations of the categories, and next relabeled the case studies independently. A case study may have multiple labels.

Table 2(a) shows the legend used in Tables 2(b) and (2c); the latter two tables show the association matrices for the two coders. Thus, the first row in Table 2(b) says that 34 case studies (out of the total 74) were labeled as problem decomposition, 14 had the labels problem decomposition and compound analogy, and so on.

Table 1: Description of the semantic labels on the case studies.

Semantic Label	Description
Problem Decomposition	The case study contained a functional decomposition of the problem.
Compound Analogy	The resulting design contains elements from two or more biological analogues.
Problem Reformulation	The case study specifically mentioned that the problem changed due to some reason.
Problem-Driven Design	The case study started with a problem and a solution for the problem was generated
Solution-Based Design	The case study started with a design pattern from biology and a problem was found that could be addressed with the pattern.
Environmental Impact Analysis	The case study contained such an analysis.
Mechanics	Some form of movement was critical to the proposed design
Materials	The proposed solution emphasized a particular material that was more beneficial than another
Sensing	The design contained some form of sensing mechanism derived from biology
Physiology	The solution used as inspiration a pattern (mechanism, principle, structure, form) related to the internal functioning of an organism.
Intentional Sustainability	The primary goal of the case study related to sustainability
Serendipitous Sustainability	The case study did not mention sustainability, but the solution was sustainable

Table 2(a): Legend for Tables 2(b) and 2(c)

PD	Problem Decomposition	ME	Mechanics
CA	Compound Analogy	MA	Materials
PR	Problem Reformulation	SE	Sensing
PB	Problem-Based Design	PH	Physiology
SB	Solution-Based Design	IS	Intentional Sustainability
EI	Env. Impact Analysis	SS	Serendipitous Sustainability

Table 2(b): Association Matrix for Coder 1

	PD	CA	PR	PB	SB	EI	ME	MA	SE	PH	IS	SS
PD	34	14	2	32	2	20	20	19	5	16	16	3
CA	14	31	3	31	0	19	13	20	4	15	13	2
PR	2	3	3	3	0	1	1	2	0	3	1	0
PB	32	31	3	65	0	33	35	37	8	33	25	5
SB	2	0	0	0	9	1	6	3	1	8	1	0
EI	20	19	1	33	1	34	17	22	3	16	19	3
ME	20	13	1	35	6	17	41	18	3	22	12	3
MA	19	20	2	37	3	22	18	40	0	21	14	4
SE	5	4	0	8	1	3	3	0	9	2	2	0
PH	16	15	3	33	8	16	22	21	2	41	17	1
IS	16	13	1	25	1	19	12	14	2	17	26	0
SS	3	2	0	5	0	3	3	4	0	1	0	5
Total	**34**	**31**	**3**	**65**	**9**	**34**	**41**	**40**	**9**	**41**	**26**	**5**

	PD	CA	PR	PB	SB	EI	ME	MA	SE	PH	IS	SS
PD	34	14	2	29	5	20	16	21	6	15	16	3
CA	14	31	4	31	0	19	13	22	4	14	11	2
PR	2	4	4	4	0	2	1	3	0	3	1	0
PB	29	31	4	62	0	31	28	42	7	30	23	5
SB	5	0	0	0	12	2	10	4	3	7	1	0
EI	20	19	2	31	2	33	15	22	3	13	18	3
ME	16	13	1	28	10	15	38	20	4	18	8	2
MA	21	22	3	42	4	22	20	46	1	25	14	5
SE	6	4	0	7	3	3	4	1	10	3	2	0
PH	15	14	3	30	7	13	18	25	3	37	14	0
IS	16	11	1	23	1	18	8	14	2	14	24	0
SS	3	2	0	5	0	3	2	5	0	0	0	5
Total	**34**	**31**	**4**	**62**	**12**	**33**	**38**	**46**	**10**	**37**	**24**	**5**

Table 2(c): Association Matrix for Coder 2

Cohen's kappa coefficient was used to measure the degree of agreement between two coders: the kappa score was 0.88, corresponding to a 94% agreement between the coders, which is commonly considered to be very accurate.

A preliminary analysis reveals six patterns common to the association matrices 2(b) and 2(c):

(P1): *Compound analogy is rare with solution-based design.* A possible explanation for this pattern is that in the solution-based approach, designing typically starts with a design principle in a single biological system and then a problem that can be solved using the principle is identified. This leaves little room for compound analogy as it requires drawing inspiration from more than one biological analogue. A corollary of this hypothesis is that solution-based design may lead to fixation on a single analogue.

(P2): *Problem decomposition is likely to be found when problem-driven design too is found.* An explanation for this pattern appears to directly follow from the characterizations of problem-driven design and problem decomposition.

(P3) *Solution-based design is commonly found in physiology, and not as much in other domains.* This pattern initially was a surprise to us; insofar as we know, it has not been previously discussed in the literature. However, Coder 1 found that 8 out of 9 case studies that used solution-based design were in physiology; Coder 2 found the same for 7 out of 12 case studies. One possible explanation is that the domain of "physiology" affords system-level design principles that trigger solution-based design more commonly than the other three domains of mechanics, materials and sensing. This is consistent with our characterization of real domain of interest here, namely, the mechanism of internal functioning of a system, and thus at least partially validates our characterization of the domain.

(P4): *Sensing commonly uses problem-driven design, not solution-based design.* Again insofar as we know, this pattern has not been previously discussed in the literature. However, Coder 1 found that 8 out of 9 case studies in sensing used problem-driven design; Coder 2 found the same for 7 out of 10 case studies. It appears that biologically inspired design in sensing mostly begins with a problem and not a solution, perhaps because the domain presents relatively well-defined problems.

(P5) *Materials and sensing rarely occur together.* We do not presently have a good explanation for this hypothesis.

(P6) *Environmental impact analysis is seldom done with solution-based design.* Again, we do not presently have a good explanation for this hypothesis.

Section 6: Word Cloud Analysis

We generated word cloud images to visualize patterns in the documents of each of the seventy four case studies. We then aggregated the word clouds for each of the four domains: physiology, mechanics, materials, sensing. As Figure 1 illustrates, sensing shows a higher relative frequency of the verb “detect” as well as “need” compared to the other three domains.

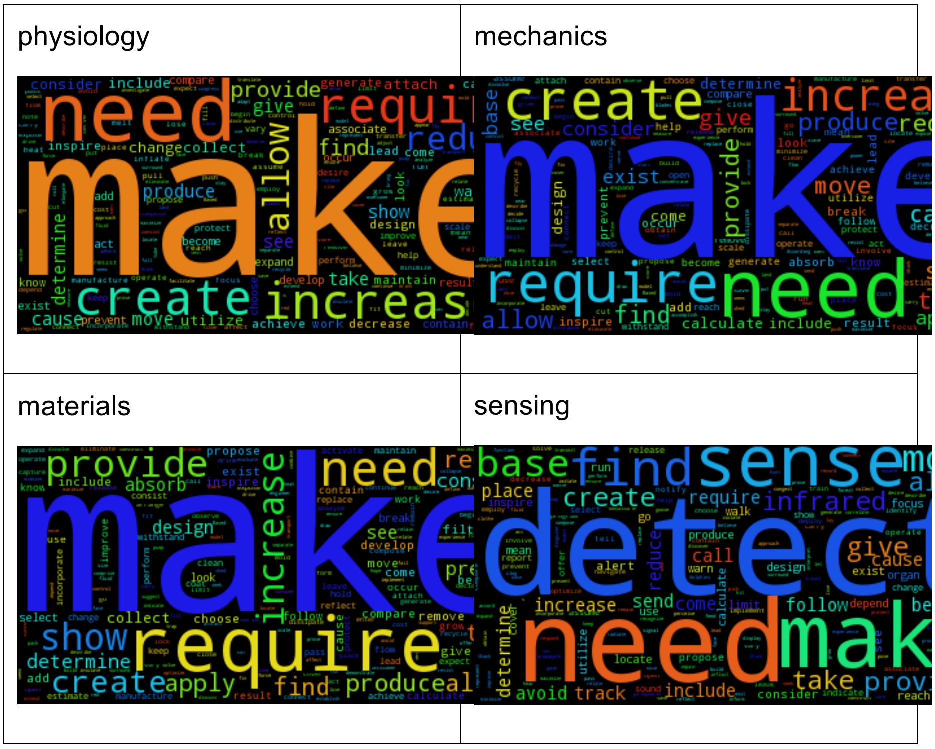

Figure 1: Verb clouds for the four domains

In addition, we compared the frequencies of six nouns for the four domains: system, function, structure, behavior, mechanism, and environment based on the Structure-Behavior-Function modeling (Goel 2013b). Figure 2 illustrates the normalized frequency of these words for the four domains. Note that case studies in the domains of physiology and sensing have a higher occurrence of noun “system”. Further, sensing has a higher frequency of “environment” and a lower frequency of “structure” compared to the other three domains.

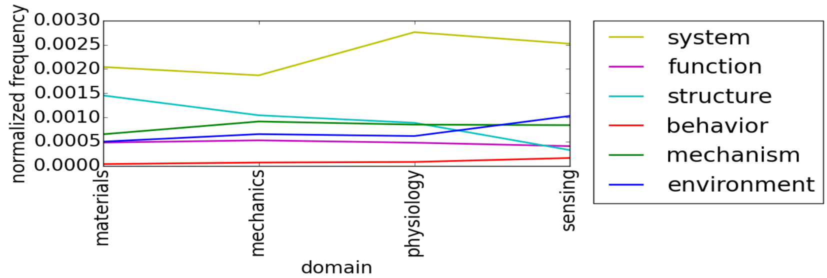

Figure 2: Frequency of selected words in the four domains.

Section 7: Statistical Analysis

We measured associations between the labels of Tables 2(b) and 2(c) using Fisher's exact test and the Pearson correlation coefficient. Fisher's exact test is a well known statistical significance test for analyzing association tables such as Tables 2(b) and 2(c). Fisher's test is appropriate for this study because the categorical nature of data in the two tables. Pearson correlation coefficient is a standard

Table 3(a): Coder 1's significant correlations.

	Tag A	Tag B	Fisher P Value	Pearsons Correlation
1	PB	CA	0.008	0.316
2	SB	CA	0.008	-0.316
3	SB	PB	0.000	-1.000
4	EI	CA	0.034	0.261
5	EI	PB	0.033	0.260
6	EI	SB	0.033	-0.260
7	SE	MA	0.000	-0.404
8	PH	PB	0.037	-0.251
9	PH	SB	0.037	0.251
10	IS	EI	0.001	0.401

Table 3(b): Coder 2's significant correlations.

	Tag A	Tag B	Fisher P Value	Pearsons Correlation
1	PR	CA	0.027	0.282
2	PB	CA	0.001	0.374
3	SB	CA	0.001	-0.374
4	SB	PB	0.000	-1.000
5	EI	PD	0.035	0.264
6	EI	CA	0.019	0.285
7	ME	PB	0.025	-0.282
8	ME	SB	0.025	0.282
9	MA	PB	0.047	0.262
10	MA	SB	0.047	-0.262
11	SE	MA	0.000	-0.425
12	IS	PD	0.024	0.288
13	IS	EI	0.000	0.424
14	IS	ME	0.047	-0.250

measure of the linear correlation between two variables *X* and *Y*, giving a value between +1 and −1, where 1 is total positive correlation and -1 is a total negative correlation.

As Tables 3(a) and 3(b) indicate, the two-tailed test with $p < 0.05$ does not confirm patterns P2 and P4. P2 refers to problem decomposition in problem-driven design: *Problem Decomposition is likely to be found when problem-based design too is found*. In retrospect, the reason for the failure to confirm this pattern is clear: while the numbers in the relevant cells in Tables 2(b) and 2(c) are fairly large (32 for coder 1 and 29 for coder 2), the proportions are relatively small compared to the number of the case studies with problem-driven design (65).

Pattern P4 pertains to the domain of sensing: (P4) *Sensing commonly uses problem-based design, not solution-based design.* We expect this is (only) because of the small sample size (10) of the case studies pertaining to the sensing domain. We note that the word cloud analysis provides additional evidence that the domain of sensing is different from the other three domains. Thus, this hypothesis requires additional investigation.

Discussion

In this section, we critique this work from the perspectives of (i) research methodology, (ii) design theory, and (iii) limitations of the current study. We also discuss some directions for future work.

First, from the perspective of research methodology, while biologically inspired design is a well-known paradigm, systematic research of the design paradigm is relatively new. Much research on biologically inspired design appears to be based on informal retrospective analysis of a small number of skeletal and anecdotal case studies. There is a need for more rigorous analysis of larger samples of case studies of biologically inspired design.

Vattam, Helms & Goel (2007) analyzed seventy seven case studies of biologically inspired design. While sixty of the case studies were reported in the design literature, seventeen were taken from the Georgia Tech ME/ISyE/MSE/PTFe/BIOL 4740 course (and are now a part of the DSL digital library). The previous research resulted in several findings, for example, (a) biologically inspired design is characterized by two core design methods, namely, problem-driven design and solution-based design, and (b) compared to problem-driven design, solution-based design often results in multifunctional design but runs the risk of fixation on the design structure. In contrast, this paper explores the role of domain in the design processes. Note that pattern P1 in the current study (*Compound analogy is rare with solution-based design)* appears to confirm the second half of the (b) pattern from the previous study.

A related methodological point is about the importance of digital libraries of case studies of biologically inspired design such as DSL. As Goel et al. (2015) note, digital libraries such as DSL enable systematic documentation and analysis; this research would be much harder to conduct without DSL.

Second, from the viewpoint of design theory, there long has been a debate about the domain independence of design tasks and methods (e.g., Chandrasekaran 1990; Cross 2006; Dym & Brown 2012; Eastman, Newstetter & McCracken 2001; Goel 1997; French 1985; Simon 1996). On one hand, design disciplines such as architecture, engineering and computing have developed many domain-specific design theories. Within computing, the design domains of computational architecture, software, and interface have developed their own domain-specific design theories. Yet, there also appears to be a degree of generality to many design tasks and methods across various domains. Indeed, the search for this design generality is one of the motivations for the conference series on Design Computing and Cognition.

Kannengiesser & Gero (2015) have argued that their Function-Behavior-Structure framework for design captures the generality of design processes across the domains of engineering, software and service design. However, Vermaas (2013) has enumerated several meanings of "function" within engineering itself, and Goel (2013b) has described the evolution of the meaning of "function" within the Structure-Behavior-Function theory of system modeling: as the scope of SBF modeling evolved from problem solving to memory to learning, so did its characterization of "function". Nevertheless, it is interesting to search for levels of abstraction for capturing the generality of a design paradigm. The organizing principle of using analogies to nature for inspiring the design of technological systems and evaluating technological designs captures the unity of biologically inspired design across domains and scales.

While it is interesting to search for a level of abstraction for capturing the unity of many design processes, it is also important to search in the opposite direction of domain-specificity of many design methods. We posit that current assumptions about the domain-independence of biologically inspired design processes may have obscured important differences between domains. Given the importance of mechanics and materials in engineering, the focus of much research on biologically inspired design has been on biomechanics and biomaterials. For example, the Georgia Tech undergraduate certificate in biologically inspired design comprises of a sequence of courses starting with ME/ISyE/MSE/PTFe/BIOL

4740 and continuing with courses on biomechanics and biomaterials. However, as we conduct systematic analysis of case studies of biologically inspired design from different domains, we are beginning to find domain-specific parameters.

Third, while this study deals with a fairly large sample size, it has a few limitations. One limitation pertains to possible sample bias: as noted earlier, all case studies in DSL come from extended collaborative design projects from 2006 through 2013 in the Georgia Tech ME/ISyE/MSE/PTFe/BIOL 4740 class. While it is true that the students in this class are novice designers, it is also true that engineers in general are not necessarily experts at biology and biologists in general are not necessarily sophisticated at design. Thus, it is not clear how to characterize expertise in biologically inspired design or exactly who is an expert in it, and the results of this study might be more general than appears at first glance. Nevertheless, it is very important to replicate this preliminary study with larger samples of biologically inspired design case studies acquired from different groups of subjects such as the professional and student designers participating in The Biomimicry Institute's Design Challenges (https://biomimicry.org/design-challenges/).

Another limitation is that while the two coders in this study are familiar with biologically inspired design, neither has much formal background in biology. It might be useful to replicate this study with a different set of coders with stronger backgrounds in biology.

Yet another limitation pertains to the classification of domains. As noted earlier, we obtained the four labels classifying domains from Professor Yen, a Georgia Tech Professor of Biology and the primary instructor of the Georgia Tech ME/ISyE/MSE/PTFe/BIOL 4740 course. The rationale behind this classification apparently is that leading biology journals, such as the *Journal of Experimental Biology* and the *Journal of Bioinspiration and Biomimetics,* use it. However, as we noted earlier, "physiology" here appears to be a biological instantiation of the real domain of interest, the "bridging domain" of the mechanism of internal functioning of a system. A revised or refined classification of bridging domains may reveal additional domain-specific differences.

These limitations notwithstanding, we submit that this study raises an important question about a basic assumption of all current theories of biologically inspired design, namely that the design processes are domain independent. Thus, this study represents a necessary first step: now that it has proposed a novel hypothesis, it can be replicated and tested, and revised and refined through additional studies.

Finally, while our analysis thus far has primarily addressed the question of domain independence of the processes of biologically inspired design, it also pertains to the issue of scale independence of the design processes. As we noted in the introduction, the example of a mechanical device for water harvesting inspired by the design of mitochondria has two scales of interest: the micrometer scale of mitochondria and the meter scale of the mechanical device. However, we also said that the real domain of interest here is that of water harvesting (and neither mitochondria nor mechanical devices *per se*). We note that the design pattern for water harvesting in the Weiler & Goel (2015) example evidently is scale-invariant (or analogical transfer from mitochondria to the mechanical device would not be feasible). Thus, we posit that biologically inspired design processes likely are scale-independent. This counter intuitive hypothesis calls for analysis and testing in future work.

Conclusions

Current theories of biologically inspired design assume that the design processes are domain-independent as well as scale-independent. Current pedagogical techniques and computational tools for supporting biologically inspired design too make the same assumption of domain- and scale-independence. In this paper, we examined the assumption of domain independence by analyzing eighty three cases of biologically inspired design collected from a senior-level interdisciplinary class at Georgia Institute of

Technology over 2006-2013 and organized in a digital library called DSL. We discovered that some of the parameters in the domains of physiology and sensing appear to be different from the more common domains of mechanics and materials. In particular, we discovered that solution-based based design is commonly found in the domain of "physiology" (actually, the domain of internal functioning of systems) and not as much in other domains. While our study did not directly validate the additional finding that sensing commonly uses problem-driven design and not solution-based design, there is strong evidence in favor of this pattern as well.

Of course it is important to replicate these preliminary studies with larger samples of biologically inspired design case studies acquired from different groups of subjects and using a refined classification of domains. If these hypotheses about the differences between the parameters of the various domains hold, then they likely will have important implications not only for building new, more detailed information-processing theories of biologically inspired design, but also for developing pedagogical techniques for teaching the design paradigm as well as computational tools for supporting its practice.

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