LEARNING ABOUT AND LEARNING THROUGH BIOLOGICALLY INSPIRED DESIGN

SWAROOP VATTAM, MICHAEL HELMS & ASHOK GOEL
School of Interactive Computing, and
Center for Biologically Inspired Design
Georgia Institute of Technology

JEANNETTE YEN & MARC WEISSBURG
School of Biology, and
Center for Biologically Inspired Design
Georgia Institute of Technology

1. Introduction

Biologically inspired design (BID) uses biological systems as analogues to develop solutions for design problems. Although designers have been looking to nature for inspiration for eons, only recently is BID gaining in importance as a wide-spread movement in design for environmentally-conscious sustainable development (e.g., Benyus 1997). But it is the tendency of the "products" of BID to be radically innovative (Forbes 2005; French 1998; Vogel 2000) that makes BID an interesting case for research in design creativity.

2. Uncovering biologically inspired design

What is generally known about BID are the following: (1) BID is based on cross-domain analogies requiring expertise across disparate domains (e.g. engineering and biology), and thus is inherently interdisciplinary, (2) Since the objects, relations and processes across domains are very different, design collaborators who come from disparate disciplines typically speak very different languages. (3) Since biologists in general seek to understand designs occurring in nature whereas designers generally seek to generate designs for human needs, they typically use different methods of investigation and often have different perspectives on design. (4) The resources, such as materials and processes, available in nature to realize an abstract design concept typically are very different from the resources available in the human domain. But BID is still ill-understood, both at the level of its products and processes and at the level of its cognitive underpinnings.

We undertook a cognitive study of BID in Fall 2006 in the context of an introductory course on BID. ME/ISyE/MSE/PTFe/BIOL 4803 is a project-based learning class at Georgia Tech, in which about 45 students work in small teams of 4-5 designers on assigned projects. The projects involve identification of a design problem of interest to the team and conceptualization of a biologically inspired solution to the identified problem. Each team typically had one designer from biology and a few from different engineering disciplines. We attended all the classroom sessions, collected all course materials, documented lecture content, and observed teacher-designer and designer-designer interactions in the classroom. We also observed interdisciplinary teams of designers engaged in their projects.

Some of the main findings of this study, more thoroughly documented in Vattam *et al.* (2007), include:

- Designers engaged in BID adopted two different approaches for arriving at their design solutions based on two different starting points. In a *problem-driven approach*, we observed that designers identified a problem which formed the starting point for subsequent problem-solving. They usually formulated their problem in functional terms (e.g., stopping a bullet). In order to find biological sources for inspiration, designers "biologized" the given problem, i.e., they abstracted and reframed the function in more broadly applicable biological terms (e.g., what characteristics do organisms have that enable them to prevent, withstand and heal damage due to impact?). They used a number of search strategies for finding biological sources relevant to the design problem at hand based on the biologized question. They then researched the biological sources in greater detail. Important principles and mechanisms that are applicable to the target problem were extracted to a solution-neutral abstraction, and then applied to arrive at a trial design solution. In the *solution-driven approach*, designers began with a biological source of interest. They understood (or researched) this source to a sufficient depth to support extraction of deep principles from the source. This was followed by finding human problems to which the principle could be applied. Finally they applied the principle to find a design solution to the identified problem.
- We noted how the problem-driven process was "given" to the designers by the experts as a normative methodology for biologically inspired designing, while the solution-driven process emerged in practice.
- We found that once a biological solution is selected, that solution constrained the rest of the design process in many ways. For instance, when the process was solution-driven, the initial source fundamentally drove the design process, from problem definition through final design. On the other hand, in the problem-driven process, a selected biological

solution became a source of design fixation, limiting the range of possible designs.

- We also found that designers consistently fell prey to a common set of mistakes (judged by experts/instructors) like vaguely defining problems, over-simplification of complex functions, using “off-the-shelf” biological solutions, solution fixation, misapplied analogy, improper analogical transfer, etc.

3. Learning through Biologically inspired design

BID is an instance of *analogy-based design*, which has been well researched within the design community. But a careful analysis of BID using existing theories of analogy-based design throws up surprises at every turn, suggesting that BID can act as a vehicle to gain deeper insight into design cognition and push the boundaries of existing theories. A case in point is our finding about *compound analogical solutions* in our study. We noted that a substantial number (about 66%) of design solutions generated by designers were compound analogical solutions – the overall solution is obtained by combining solutions to different parts of the problem where solution to each part is analogically derived from a different (biological) source. For example, in one design project the goal was to conceptualize surfboard technology that prevented the formation of the surfboard silhouette to prevent hit-an-run shark attacks due to mistaken identity. The final solution was a combination of (1) the concept of a ventral light glow (inspired by pony fish) that gives off light proportional to the ambient light for the purposes of counter-illumination and (2) the principle of photo-reception from surrounding light inspired by the brittle star (closely related to starfishes) for powering the counter-illumination rather than having to use energy to self-produce light.

Most existing models of analogical design are single source-based solution generation models. That is, given a target design problem, the process proceeds to retrieve a suitable analogue (within-domain or cross-domain) and modifies or adapts the retrieved design to generate a solution to the target problem. But existing models also need to explain the generation of complex designs documented in our study. Our in situ observations also revealed that as designers navigate a problem space, they implicitly decompose the problem into sub-problems. When we made the decompositions explicit, it became apparent how the process of problem decomposition and analogical reasoning work in conjunction, leading to compound analogical solutions. This led to the development of our novel conceptual framework for compound analogical design that combines those two processes. The next step in this direction would be to develop computational cognitive models that can be used to support and test our conceptual framework.

4. Supporting designers engaged in biologically inspired design

The insights gained from our cognitive studies have implications for the development of better design methods and creativity support tools in the context of BID. We have identified some of the steps that we need to take in order to support designers and are in the process of implementing some of them:

- Develop normative BID process that improves upon existing processes to overcome the difficulties and limitations that designers face (as noted in our studies)
- The creation of a knowledge-base of biological systems that can be organically grown (e.g. Wikipedia, Encyclopedia of Life)
- Develop a common language for (1) representing these systems and their functions, and (2) establishing common-ground between biologists and engineers who typically speak different languages
- Develop methods for interactive retrieval and generation of analogues for a given design problem
- Develop visualization techniques for making sense of the vast network of relations that exists between different systems at various levels of abstraction
- Develop a design environment that encompasses the above computational tools and supports our normative process

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