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Reducing cognitive bias in biomimetic design by abstracting nouns

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ABSTRACT

Biological analogies can increase creativity in design by providing related, yet distant-domain stimuli, which have been reported to lead to more innovative concepts than within-domain stimuli. However, over the past decade, we have observed that designers are influenced by cognitive biases in their selection and application of biological analogies. We propose that abstraction of biological nouns in descriptions of biological phenomena can reduce such cognitive bias and support analogical reasoning. Experiments confirmed the promising effect of this objective and automatable intervention on novice designers. The cognitive biases and fixation we aim to reduce are relevant to conceptual design in general.

1. Introduction

Biomimetic, or biologically inspired design, is gaining prominence as a design method, and has produced a number of innovative engineering solutions [1–6]. One approach developed to support biomimetic design takes advantage of the abundant biological information readily available in natural-language format, e.g., texts, papers, online resources, etc. [7,8]. In this approach, designers use keywords to locate relevant biological phenomena from text describing biological information.

Over the past decade, we have observed that designers' cognitive biases often impede the identification of analogous relationships between text descriptions of biological phenomena and potential design solutions [7].

1.1. Analogical application of biological phenomena

Biomimetic design aims to develop engineering solutions based on strategies found in biological phenomena. Identifying relevant strategies requires analogical reasoning, which involves finding similarities in *higher-order relations* between two concepts [9]. One type of a higher-order relation is a causal relation.

For example, in "Enzymes destroy bacteria to protect animals," a causal relation formed between the functions of "destroy" and "protect" identifies how a certain action is enabled in the phenomenon. This enabling strategy can be transferred to solve a design problem with the goal of achieving protection.

Identifying and transferring causal relations are essential to more general design-by-analogy methods in engineering [10,11]. These methods are often extended to model biological systems and support biomimetic design [12,13].

1.2. Non-analogous application of biological phenomena

We often observed that novice designers, e.g., final-year undergraduate engineering students participating in biomimetic design exercises, use non-analogous association to apply suggested biological phenomena in their design solutions [14–17]. This is often initiated by fixation on specific words and phrases, referring to either entities or functions, in the descriptions of biological phenomena. For example, a student presented with the above description of enzymes may develop solutions based on other perceived or known characteristics, e.g., ribbon shape, of enzymes. In this case, the student fixates on enzymes over other entities or functions present in the description. The student then uses prior knowledge, i.e., ribbon shape, of enzymes, to develop a solution that is not analogous to the provided phenomenon.

In addition to the above obstacle, other cognitive biases reported include the tendency by novice designers to develop the same concept multiple times in response to different analogies intended to solicit different solutions [15,16]. Analogies are also often matched with existing and widely known solutions, rather than used to develop new solutions, even by experts, i.e., collaborators in academia and industry. Goel et al. [13] report similar cognitive biases by student designers conducting biomimetic design projects. Such cognitive biases and fixation are obstacles that are relevant to conceptual design in general.

1.3. Previous methods to support application of biological analogies

Mak and Shu first proposed the use of "templates" to aid students in analogical transfer [15,16]. Cheong and Shu developed a template that asks designers to identify causally related functions from descriptions of biological phenomena [17].

Cheong and Shu [18] then developed a computational technique to automatically identify causally related functions based on grammatical relations. This enabled a search tool to sort descriptions of biological phenomena by the enabling functions of the desired function. This technique is intended to help designers focus on functional relations rather than specific entities that could cause fixation or non-analogous association.

However, in 96 concepts developed by final-year engineering students using the above tool, 43% still exhibited fixation on specific entities. For example, using the above phrase describing

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