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COMMENT

Comment on "Innovation through imitation: biomimetic, bioinspired and biokleptic research" by A. E. Rawlings, J. P. Bramble and S. S. Staniland, *Soft Matter*, 2012, 8, 6675

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We try to clarify some issues that were raised by an article that appeared in *Soft Matter*, 2012, **8**, 6675. The main question was how to distinguish biomimetic, bioinspired and biokleptic research. We put forward a "continental" perspective that can help to avoid some of the confusion that might have been evoked.

Everybody is free to define a scientific field as she or he wishes. This also applies to biomimetics and related fields. There is, however, already a tradition of describing these areas, admittedly with variations in different parts of the world. The authors of the paper "Innovation through imitation: biomimetic, bioinspired and biokleptic research", which appeared in this journal,[1] attempted to put into order some of the notions of the relevant research areas. We are not entirely convinced by everything they said. Hence, we would like to put forward a "continental" perspective to the issues raised in their paper, in particular because a huge amount of literature is available on *Bionik* – the German equivalent of biomimetics.[2] We do not strive to put normative boundaries to different disciplines, as they are still floating and will remain so in the future. Nonetheless, some clarification is in order.

Rawlings *et al.*[1] equate biomimetics with biomimicry without any explication. The term biomimicry is becoming ever more popular and sometimes replaces biomimetics. Biomimicry, however, as popularized by Benyus,[3] deviates slightly from biomimetics in its method. Biomimicry places prime importance on sustainable, environmentally friendly solutions. Biomimetics, in contrast, does not explicitly include this sustainability aim in its method.

More importantly, biomimetics is about transferring principles from biology to engineering. "Biomimetics is the abstraction of good design from nature" one reads on the website of the Centre for Biomimetics (University of Reading, UK).[4] Hence, its essence is understanding the principle behind a phenomenon, through abstraction, and subsequently applying this very principle in engineering (Fig. 1). Mere copies are therefore not regarded as *Bionik*.[5] What you consistently hear in German reflections on biomimetics is that 1 : 1 copies are not the solution. The reason is that such applications often fail to function, unless one understands the principle behind a particular form, process or development. Starting from the mere etymology of the terms *bios* and *mimetikos* and concluding that "at the heart [biomimetics] is simply the imitation of living organisms"[1] is not the proper approach.

The following recent definition – produced by leading experts in biomimetics in Germany – solves this problem by focusing primarily on abstraction: "Biomimetics combines the disciplines of biology and technology with the goal of solving technical problems through the abstraction, transfer, and application of knowledge gained from biological models".[2] [Reproduced with the permission of the Verein Deutscher Ingenieure, VDI, e. V.] Abstraction, in this definition, involves the finding of principles of function or operation.[2]

Easily available definitions are often fuzzy and metaphorical, including expressions such as "inventions of nature"[6] (in the definition of *Bionik*), "good design from nature"[4] (in the definition of biomimetics), or "nature's best ideas"[7] (in the definition of biomimicry). Intuitively, such expressions appear to be clear. Nonetheless, they fail to stand the test of severe scrutiny. Starting with such weak definitions, one can always argue whether something is part of the game or not, especially when it is close to the boundaries. Logically, one cannot reason accurately whether something is covered by the field of biomimetics when the definition is fuzzy (*cf.* Gupta[8]). In this regard the VDI definition is clearer than others.

Nachtigall[5] employs the term *Technische Biologie*, which seems to be useful with regard to the issue raised by Rawlings *et al.*, who questioned whether parts of what they do is biomimetics or not. *Technische Biologie* can be translated as Technical Biology[9] and describes the investigation of biological systems with methods and tools from engineering. As basic research, it is a necessary and complementary area with regard to later

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applications. First, the biological phenomena are investigated (technical biology) to find principles that can then be utilized in engineering through applied research (biomimetics). Biomimetics in this narrow sense (knowledge transfer to engineering) can be distinguished from technical biology (knowledge transfer to biology). One can also couple them and refer to biomimetics in a broad sense because the biomimetic application is not possible without doing technical biology beforehand. Biology can gain from investigations in both approaches: with technical biology this is straightforward but, equally, new insights for biology can arise when transferring knowledge from biology to engineering. The latter case is termed "reverse biomimetics".[2]

There is no sharp boundary between biomimetics and biotechnology. If there is no transfer of an abstracted principle, however, it is incorrect to refer to biomimetics. If the end result of a biological and an engineering process is the same, this does not indicate that biomimetics is involved. This distinction also holds true for biomimetics *versus* biokleptic. As the use of the term biokleptic already indicates, it is not necessarily about transferring an abstracted principle.

Rawlings *et al.* state at the end of their article: "The important question to ask when considering whether an experiment, product, reagent, material or technology is a biomimetic is not how the component is synthesised, by nature or a scientist, but rather—who is in control? Is it the scientist or nature?".[1] Here, the term "a biomimetic" is unusual, but more importantly, biomimetics cannot be distinguished from non-biomimetics by determining who is in control – whatever "being in control" might actually mean.

Bioinspired research or design are broader labels than biomimetics, also involving mere copies of form or the inspiration an artist uses when looking at living nature in order to create a piece of art. Everything biomimetic is also bioinspired, but not the other way round. Accordingly, Art Nouveau furniture is bioinspired but not biomimetic, as there is no transfer of a functional or organizational principle.

To introduce a figure (as Fig. 1 in Rawlings *et al.*) and invite the reader to allocate various processes and products to the fields bioinspired, biotechnology, biokleptic and biomimetics is not very useful; even more so as they "attempt to describe each area with definitions, examples and discussion".[1]

Before defining something, one has to ask for the purpose or aim of such a definition. Now, *Bionik*/biomimetics sells. The terms are used (or even misused) in an inflationary way. This no doubt explains why researchers try to set up a widely accepted definition for their field. The Association of German Engineers

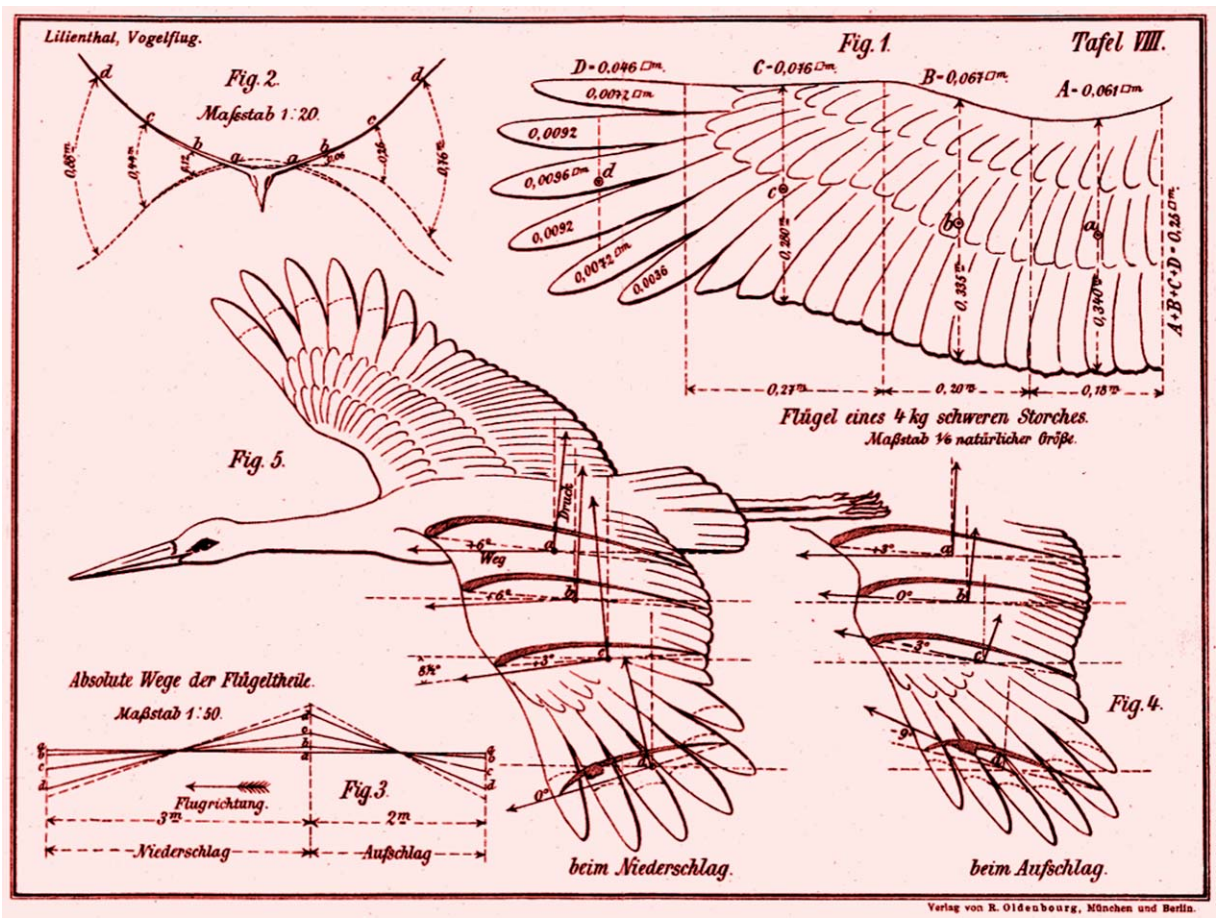

Fig. 1 Lilienthal's work serves as a good example for biomimetics, including abstraction, transfer, and application of knowledge gained from biological models (*cf.* VDI definition[2]). Image source: O. Lilienthal, Der Vogelflug als Grundlage der Fliegekunst, Gaertners Verlagsbuchhandlung, Berlin, 1889. (Facsimile by Oldenbourg, München, 1943).

(Verein Deutscher Ingenieure – VDI) produced a guideline for biomimetics – including the above mentioned definition of biomimetics.[2] One goal was to distinguish products for which biomimetics was really used from products for which biomimetics merely serves as an advertising ploy. Another purpose of the definition is to provide a conceptual and methodical framework for education and research.

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