INTERNATIONAL DESIGN CONFERENCE - DESIGN 2014
Dubrovnik - Croatia, May 19 - 22, 2014.

BIOSCRABBLE – THE ROLE OF DIFFERENT TYPES OF SEARCH TERMS WHEN SEARCHING FOR BIOLOGICAL INSPIRATION IN BIOLOGICAL RESEARCH ARTICLES

M. K. Kaiser, H. Hashemi Farzaneh and U. Lindemann

Keywords: biologically inspired design, solution search, search terms

1. Introduction

Why are technical properties highly relevant when searching for biological solutions for the design of a self-sharpening knife whereas technical functions or a technical system's environment play a key role when searching for biological solutions for purifying water?

In the last decades, engineers have increasingly been driven by the question of how nature can be discovered and used for developing innovative technical solutions. Methods and tools have been developed to support engineers either in searching biological inspiration for answering technical questions – which is in the focus of this work – or for transferring biological principles into technical products. Searching for biological inspiration has been assisted either by the provision of biomimetic databases [http://www.asknature.org], [Hill 1997], [Gramann 2004], [Chakrabarti et al. 2005], [Löffler 2008], or by supporting an effective use of biological knowledge that is available in text format, e.g. textbooks (research on this area is discussed in detail in chapter 2).

In case of using available biological literature, the disadvantages of databases such as to be initially filled or kept up-to-date do not exist. However, dependent on the type of biological literature that is used for searching, another challenge occurs: the finding of biological inspiration in a potentially big and specialized information source. This is especially true for biological research articles. Nevertheless, biological research articles are a promising biological search source as they represent the past and ongoing biological research and therefore offer a great number of relevant research results including the latest findings.

Here, it is addressed which types of search terms are useful for searching for problem specific inspiration when scanning unadapted (not adapted for engineers, e.g. simplified or tagged) biological research articles. In related research, the focus was on using technical functions as search terms or – to close the linguistic-notational gap between engineers and biologists – providing the engineer with bridge terms, thesauri or tagged biological articles. The search sources were either biology books or the world wide web. Taking only unadapted terms or literature into consideration, it was shown that more technical product descriptions and biological research articles can be mutually mapped by collating not only terms describing technical functions but also terms describing properties of technical systems or their environment [Kaiser et al. 2011]. This finding motivated the question: Do the search term categories "function", "property" and "environment" vary in their effectiveness and efficiency when searching for useful biological inspiration in unadapted biological research articles?

Following a literature survey on related research, the results as well as limitations of an empirical study on biomimetic solution search are illustrated and discussed.

2. Related research

This chapter provides an overview of search terms and search sources researchers focused on for supporting an effective discovery of biological information available in text format for biologically inspired design.

2.1 Search terms

A natural language approach to biomimetic design has been developed at the University of Toronto. To search for useful biological analogies in biological literature, primarily verbs describing desired technical functions or effects were used as search terms [Shu 2010], [Cheong and Shu 2012]. The use of adjectives describing desired technical qualities like shape were only discussed by Ke et al. [2010]. Nouns were neglected as they were found to indicate preconceived solutions [Shu 2004, 2010].

Stroble et al. [2009] and Nagel et al. [2010] developed an engineering-to-biology thesaurus to provide engineers with biological search terms that are correlated to the engineering domain. These biological terms are based on the functional technical terms or terms of the Functional Basis (characterization of product functions in a verb-object (function-flow) format [Stone and Wood 2000]. Nagel and Stone proposed a methodology which aims at facilitating systematic biologically inspired design. In this methodology, the functional terms contained in the above named thesaurus play a central role in searching for biological analogies [Nagel and Stone 2011].

For finding biological analogies, also Vandevenne et al. [2011] concentrated on functions or functional verbs of technical or biological systems.

As all of these approaches focus on functions to support searching for biological inspiration for technical questions in biological literature, it is worth examining also the role of searching by properties of technical systems or their environment. Vattam and Goel [2011], e.g., observed that – in case the designer is not supported in searching nor asked to use specific types of search terms – information about a system's operating environment plays a role in searching analogies in biological literature in addition to functional information.

None of the approaches described above examined in particular which search terms or types of search terms are useful for searching for biological inspiration when focusing on biological research articles as a search source.

Though these articles are included in approaches supporting searching for biological inspiration in the World Wide Web, the following subchapter shows that in these approaches the focus was more on processing the web than on supporting the selection of promising search terms. The latter issue was mainly examined based on biological textbooks.

2.2 Search sources

To support an effective discovery of biological information available in text format, keyword searches were performed and analysed using an introductory biological textbook at the University of Toronto. The textbook was chosen as an initial text source, because 1) it is intelligible for a reader without a biological background and 2) it provides biological information ranging from molecular structures to ecosystems [Shu 2010], [Cheong and Shu 2012]. Advanced sources such as biological research articles are suggested for finding further details on selected biological analogies rather than for initial searching [Shu 2010].

Biological textbooks were also used by Stroble et al. [2009] and Nagel et al. [2010] for compiling their engineering-to-biology thesaurus and by Nagel and Stone [2011] for testing the above named methodology for facilitating systematic biologically inspired design – including searching for biological analogies.

The use of the World Wide Web – including biological research articles – as an initial biological search source was explored and supported by Vandevenne et al. [2011, 2012]. The web was also analysed as an initial search source by Vattam and Goel [2011]. Whereas Vandevenne et al. developed a webcrawler that continuously collects documents containing biological information that is relevant to biomimetics, Vattam and Goel proposed a social citation cataloguing system. In this system, designers can post citations or do model-based tagging of biological articles they found useful for biologically inspired design.

3. Research questions

Based on the previously described finding that more technical product descriptions and biological research articles can be mutually mapped by collating not only terms describing technical functions but also terms describing properties of technical systems or their environment [Kaiser et al. 2011], a biomimetic search support called BIOscrabble was developed [Kaiser et al. 2013]. In this work, BIOscrabble, for the first time, was used for biomimetic solution search in an empirical study to address the following research questions:

1. *Which of the search term categories "function", "property" and "environment" is most effective when searching for biological information which is inspiring for solving a technical problem in biological research articles?*
2. *Which of the search term categories "function", "property" and "environment" is most efficient when searching for biological information which is inspiring for solving a technical problem in biological research articles?*

Here, "effective" and "efficient" are defined as follows: a search term category is the more "effective" the higher the number of inspiring biological research articles which contain search terms of this category; a search term category is the more "efficient" the lower the percentage of search terms of this category which are not contained in an inspiring biological research article.
In the next chapters, the authors provide an indication of the role single search term categories can play when searching for biological inspiration for a technical problem – in relation to that specific problem.

4. Empirical study

In this chapter, the design of the empirical study – carried out to answer the research questions formulated above – as well as the search support BIOscrabble is illustrated. The study design is accompanied by an example for a solution search for a technical problem, namely the conceptualization of a self-sharpening knife (s-sk), to clarify the study procedure.

4.1 Study design

For solving seven different technical problems, seven students of mechanical engineering searched for biological inspiration. All students had been studying mechanical engineering for at least two years. They performed the biomimetic solution search in the context of their bachelor theses or term papers. The solution search was supported by a part of the search support BIOscrabble which all students were asked to adhere to. Taking the results of a pilot study and the empirical study into account, BIOscrabble was and is further developed to a tool to also computationally support the managing of a large number of search results [Kaiser et al. 2013].
The study design was carried out as follows:

1. Each student chose a technical problem based on interest. The problems the students searched biological inspiration for were to conceptualize a device for purifying water, an adaptable cooking pot surface with variable heat conductivity, a self-sharpening knife, an aquaplaning-reducing car tire, a tension-reducing mechanism for luggage, a nonelectronic hairdrying comb and an improved cable tie for a Sardinian water pumping system.
2. For searching for biological inspiration for their chosen technical problem, the students used the search support BIOscrabble. BIOscrabble is explained in detail in chapter 4.2. BIOscrabble search results are research articles which match the search terms or phrases it is searched by. For the s-sk, search results were, e.g., articles about sea urchin teeth and crab claws.
3. For the selection of biological research articles, the titles and abstracts of the search results were scanned. Articles which each student considered to contain biological information that is inspiring for solving the chosen technical problem were selected by different selection criteria. For the s-sk, the selection was performed by, first, reducing the number of search results through NOT-searches and then setting up knock-out criteria. A useful NOT-search was, e.g., performed via the search phrase "self-sharpening NOT electrophoretic". A useful knock-out criterion was, e.g., "the paper is treating a medical application".

4. The selected articles were further examined by the students with the help of sources like books or internet contributions. Here, no methodological support was provided.
5. Each student incorporated or combined one or more of the selected articles' contents in a bio-inspired concept or prototype which aimed at solving the chosen problem. For the s-sk, the article about sea urchin teeth was incorporated.

4.2 BIOscrabble

The part of BIOscrabble which was used in the empirical study is illustrated in figure 1.

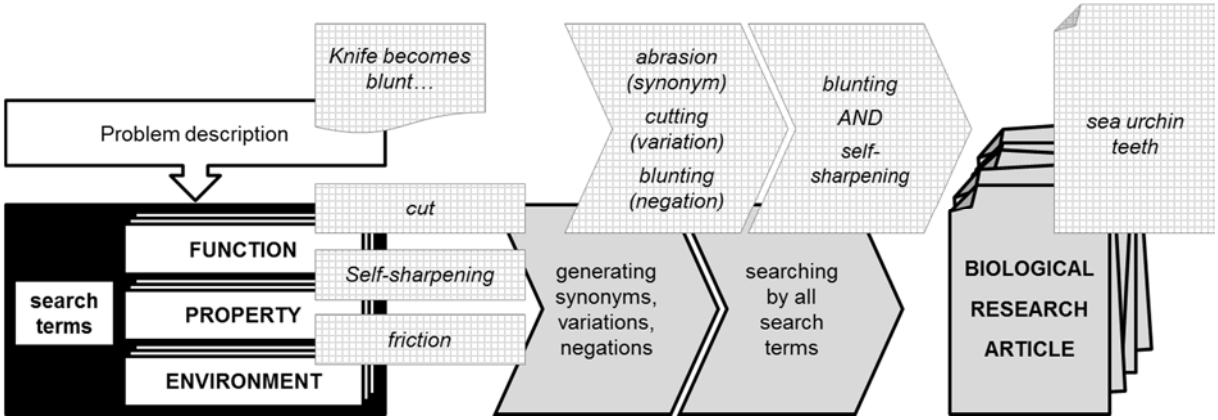


Figure 1. BIOscrabble as used in the empirical study accompanied by the example of the s-sk

It comprises the following steps:

1. A technical problem is described in terms of the technical functions the desired technical system shall fulfil, the properties it shall possess and the environmental influences it shall cope with. The terms for searching for biological inspiration are derived from that description and assigned to the search term categories "function", "property" and "environment" which are defined as follows:
   - Function: „the intended input/output relationship of a system whose purpose is to perform a task" [Pahl et al. 2007]
   - Property: „A property is anything that is possessed (owned) by an object (a TS)" [Eder and Hosnedl 2008] where TS is the abbreviation of technical system; Eder and Hosnedl defined several classes of properties. In BIOscrabble it is focused on the classes "Internal Properties" and "Purpose Properties". Within the latter "functions properties, effects properties" are excluded as technical functions are regarded separately.
   - Environment: all environmental effects on a technical system as well as the interplay between a system and its environment

   In the following, search terms of the categories "function", "property" and "environment" are referred to as F-terms, P-terms and E-terms. For the s-sk, a F-term was, e.g., "cut", a P-term was, e.g., "self-sharpening" and a E-term was, e.g., "friction".
2. The search terms' synonyms, variations (noun-, verb-adjective-forms), and negations can be derived in order to broaden the solution space and at the same time to enhance the differentiation of the terms. The latter accounts for the differences between the terminologies designers and biologists use to describe their work. Synonyms and variations can be partly generated by using the lexical database WordNet [http://wordnet.princeton.edu]. For the s-sk a synonym was, e.g., "abrasion" for "friction", a variation was, e.g., "cutting" for "cut" and a negation was, e.g. "blunting" for "self-sharpening".
3. Using the original search terms as well as their variations, the metadatabase PubMed [http://www.ncbi.nlm.nih.gov/pubmed] is searched for biological research articles. Single search terms can be connected by Boolean Operators. For the s-sk a useful search phrase was, e.g., "blunting AND self-sharpening".

4. The search results are research articles which match the search terms or phrases it was searched by.

5. Study results and discussion

Chapter 5 shows the data obtained in the empirical study as well as their analysis and indications. The students scanned 3416 biological research articles out of 6044 PubMed search results. Out of the 3416 articles scanned, 115 articles were considered inspiring for the given problem and, therefore, selected.

5.1 Results and discussion regarding the search term categories' effectiveness

The data obtained in the empirical study were examined regarding the search term categories' – "function", "property" and "environment" – effectiveness when searching for inspiring biological information for solving a technical problem in biological research articles.

Figure 2 illustrates the effectiveness of the search term categories averaged over all technical problems that have been addressed. It shows – for each of the search term categories – the percentage of selected biological research articles which contain search terms of this category.

F-terms were contained in 69% of the selected biological research articles, whereas P- and E-terms were contained in 45% and 60%, respectively.

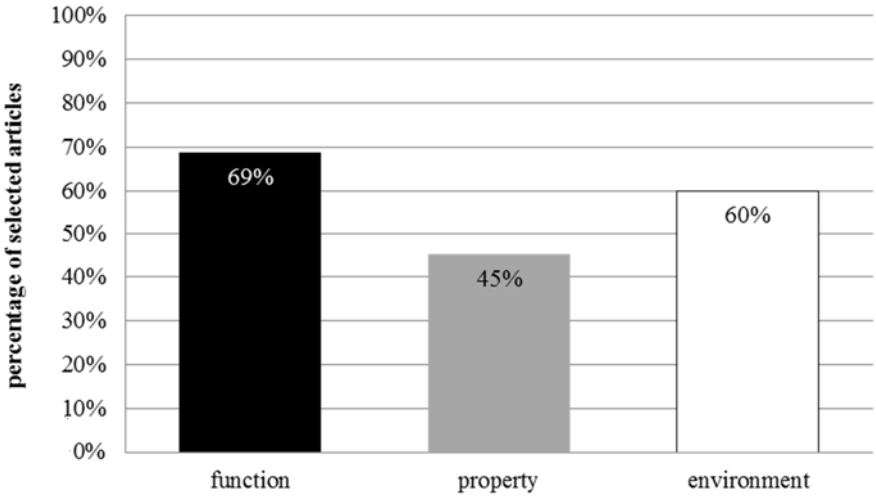


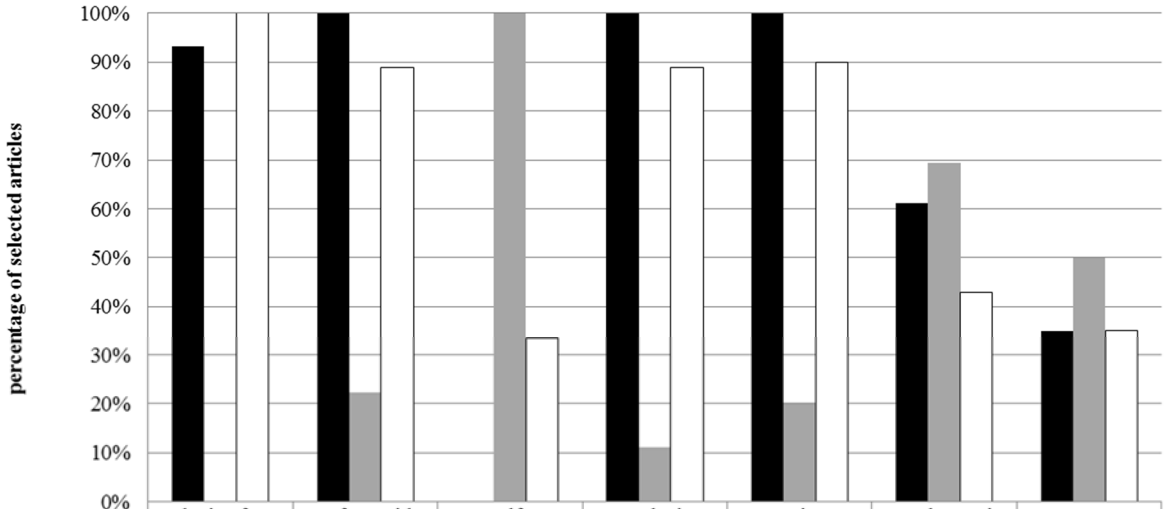
Figure 2. Percentage of all selected biological research articles which contain search terms of the search term categories "function", "property" or "environment"

Considering the technical problems addressed separately, the results are different. Figure 3 shows – now for each of the search term categories and for each of the technical problems – the percentage of selected biological research articles which contain search terms of the single categories.

In case of the device for purifying water, the adaptable cooking pot surface with variable heat conductivity, the aquaplaning-reducing car tire and the tension-reducing mechanism for luggage, F- and E-terms were most prominent in the selected biological research articles. In case of the self-sharpening knife, the nonelectronic hairdrying comb and the improved cable tie for a Sardinian water pumping system, P-terms were most prominent in the selected biological research articles. This was especially true for the former. For the comb and the cable tie the differencies between the categories were not very pronounced.

Taking the study's raw data into account, F-terms occurred together with E-terms in all selected biological research articles. i.e. articles that were considered to contain biological information that is inspiring for solving the given technical problems. It appears that searching for particular biological inspiration by E-terms in addition to F-terms had a positive effect on the usefulness of the search results. A positive effect of information about a system's operating environment on finding analogies for technical problems in biological literature was also indicated by Vattam and Goel [2011]. A possible reason for this effect is that a biological system's functional capacity is strongly aligned to the

environmental influences it is exposed to – as biological systems evolve driven by their environment. Another finding indicates a further benefit of searching by E-terms. As reported by the students, during searching it was useful to combine F- or P-terms with E-terms in order to reduce the number of search results which were not related to the problem addressed.



	device for purifying water	surface with variable heat conductivity	self-sharpening knife	aquaplaning-reducing car tire	tension-reducing mechanism	nonelectronic hairdrying comb	cable tie
■ function	93%	100%	0%	100%	100%	61%	35%
■ property	0%	22%	100%	11%	20%	69%	50%
□ environment	100%	89%	33%	89%	90%	43%	35%

Figure 3. Percentage of problem-specific selected biological research articles which contain search terms of the search term categories "function", "property" or "environment"

Selected biological research articles that contained a similar portion of F- and P-terms and an obviously lower portion of E-terms were rare. Nevertheless, there were technical problems for which the selected articles contained mainly P-terms – namely the self-sharpening knife, the nonelectronic hairdrying comb and the improved cable tie for a Sardinian water pumping system. In case of the knife and the comb, this can be due to the fact that both technical problems are related to the desired systems' surfaces or materials. Also in case of the cable tie, the focus was laid on the surface structure of the cable tie by the student. What is there against this assumption is the result for the aquaplaning-reducing car tire. Here, a surface related problem is addressed and – although P-terms are contained in the selected research articles – F- and E-terms form the majority of the search terms. The fact that for none of the technical problems addressed, F- or E-terms alone were contained in selected biological research articles raises the question if P-terms can be formulated more problem-specifically than F- and E-terms.

Finally, the empirical study indicates that all search term categories can be effective when searching for biological inspiration in biological research articles. It seems to be useful to combine the categories "function" and "environment". The effectiveness of the search term categories possibly depends on the technical problem that is addressed. If there is any correlation between the type of technical problem and the effectiveness of F-, P- and E-terms for finding inspiring biological research articles remains to be proven.

5.2 Results and discussion regarding the search term categories' efficiency

In addition to the search term categories' effectiveness when searching for inspiring biological research articles, the authors examined the search term categories' efficiency. A search term category's efficiency is higher the lower the percentage of the search terms used in this category which are not contained in a selected biological research article.

In the empirical study, about twice as many F-terms have been used for searching for biological inspiration as P-terms and E-terms together. Figure 4 shows that 80% of these F-terms were not contained in a selected research article. For P-terms and E-terms, it was only 50% and 58%, respectively. Hence, the search term category "function" was less efficient when searching for inspiring biological research articles than the search term categories "property" and "environment" which had a similar efficiency.

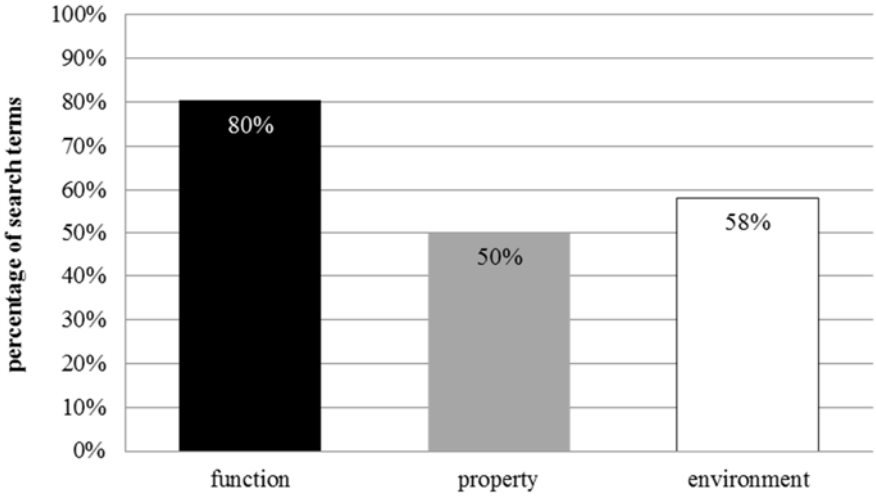
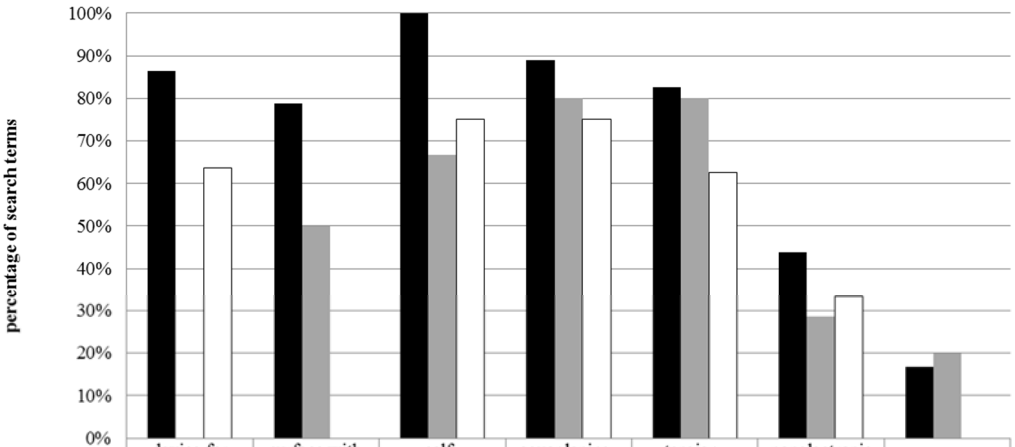


Figure 4. Percentage of all search terms in the search term categories "function", "property" and "environment" which were not contained in selected articles

When considering the technical problems addressed separately, for six out of the seven technical problems, the category "function" also showed the lowest efficiency (Figure 5). This is the case even for those problems where the search term category "function" had the highest effectiveness – namely the device for purifying water, the adaptable cooking pot surface with variable heat conductivity, the aquaplaning-reducing car tire and the tension-reducing mechanism for luggage. For the improved cable tie for a Sardinian water pumping system, the category "property" was slightly less efficient than the search term category "function".



	device for purifying water	surface with variable heat conductivity	self-sharpening knife	aquaplaning-reducing car tire	tension-reducing mechanism	nonelectronic hairdrying comb	cable tie
■ function	86%	79%	100%	89%	83%	44%	17%
■ property	0%	50%	67%	80%	80%	29%	20%
□ environment	64%	0%	75%	75%	63%	33%	0%

Figure 5. Percentage of problem-specific search terms in the search term categories "function", "property" and "environment" which were not contained in selected articles

There are two possible reasons for the relatively low efficiency of the search term category "function": 1) Technical functions were described in more neutral terms than technical properties or a technical system's environment. The specificity of the resulting F-terms therefore decreased. This led to a greater portion of terms which were not contained in any selected article in the category "function" compared to the categories "property" and "environment". 2) It came naturally to the students to describe their technical problem by technical functions – maybe due to the fact that students of mechanical engineering are trained in describing technical systems by technical functions. This resulted in a greater number of F-terms compared to P- and E-terms and therefore possibly a greater number of F-terms which are not contained in a selected article in the end.

6. Study limitations

The results of the empirical study which are shown and discussed in chapter 5 have to be seen in the context of the limitations provided below.

All technical problems were addressed by only one student each. Hence, the results they obtained are influenced by factors from the students' personalities as well as their environment and are therefore subject to a certain degree of subjectivity.

Factors from the students' personalities are factors like the students' ability to grasp new tasks or to solve problems as well as the students' long-term motivation. The students' analytical skills and creativity, e.g., determine – among others – which articles are considered useful for solving the given technical problem. This, in turn, affects the study results obtained for the effectiveness and efficiency of the search term categories.

Factors from the students' environment are, e.g., factors produced by a certain flexibility in the study design. The students were asked to present their results to the supervisor regularly, but the work space was open to choice. Therefore, there was no control over the students' work load or style which in turn can influence the quality of the study results. There was no detailed guideline for the description of the technical problems or the scanning of the search results. The students were asked to set up selection criteria for selecting articles which are considered useful for solving the given technical problem. However, no fixed selection criteria were given. The description of the technical problem, the scanning of the search results and the selection criteria were checked regarding their reasonableness and their objectivity by the supervisor. Still, no standard procedure existed which is another factor that influences the study results.

7. Conclusion

To conclude, an empirical study was carried out to examine the role different types of search terms play when searching for biological inspiration in biological research articles. Students of mechanical engineering performed solution searches on different technical problems.

According to the study results, an indication to an answer to the questions *"Which of the search term categories "function", "property" and "environment" is most effective when searching for biological information which is inspiring for solving a technical problem in biological research articles?"* and *"Which of the search term categories "function", "property" and "environment" is most efficient when searching for biological information which is inspiring for solving a technical problem in biological research articles?"* was given.

All of the three search term categories "function", "property" and "environment" can be effective when searching for biological information which is inspiring for solving a technical problem in biological research articles. The effectiveness of a single search term category possibly depends on the technical problem which is addressed. The search term categories "property" and "environment" are possibly more efficient when searching for biological information which is inspiring for solving a technical problem in biological research articles than the category "function". A possibly lower efficiency of the search term category "function" fits the finding that none of the selected articles contained only F-terms.

Altogether, when searching for inspiration for technical problems in biological research articles, the authors suggest not to focus on functional search terms, but to use search terms describing technical properties or a technical system's environment in addition.

8. Outlook

There are several issues that have to be addressed in future work to improve BIOscrabble and to further validate the results regarding the role the examined search term categories play when searching for biological inspiration in biological research articles. The empirical study will be expanded. 1) Further technical problems will be addressed. Thereby, the authors aim at finding correlations between types of technical problems and the effectiveness and efficiency of the search term categories. By this, engineers can be supported in a more specific use of search terms or phrases. 2) Problems that have been addressed will be addressed by another independent person. The aim is to reduce the degree of subjectivity of the present study results regarding the search term categories' effectiveness and efficiency. 1) and 2) aim at deriving guidelines for the scanning of search results and the selection of inspiring research articles the engineer can be provided with.

The value of searching by the original search terms' synonyms, variations (noun-, verb-adjective-forms) and negations will be examined.

To support the engineer in extracting inspiring biological information out of a big data source like PubMed, BIOscrabble [Kaiser et al. 2013] will be developed further and be implemented in a software prototype.

Studies will be carried out to assess the value of using unadapted biological research articles as an initial source of inspiration for solving technical problems compared to using other biological literature or databases.

Acknowledgements

The authors would like to thank Jan Flämig, Daniel Macnish, Markus Weis, Anna Henze, Michael Topp, Felix Kötterheinrich and Johannes Spiegel for the application of BIOscrabble and the documentation of their results.

References

Chakrabarti, A., Sarkar, P., Leelavathamma, B., Nataraju, B. S., "A Functional Representation for Aiding Biomimetic and Artificial Inspiration of New Ideas", Artificial Intelligence for Engineering Design, Analysis and Manufacturing, Vol. 19, No. 2, 2005, pp. 113-132.

Cheong, H., Shu, L. H., "Automatic Extraction of Causally Related Functions from Natural-Language Text For Biomimetic Design", Proceedings of the ASME 2012 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2012, Chicago, IL, USA, 2012, pp. 1-20.

Eder, W. E., Hosnedl, S., "Design-Engineering – A Manual for Enhanced Creativity", Taylor & Francis Group LLC, Boca Raton, FL, 2008.

Gramann, J., "Problemmodelle und Bionik als Methode.", 2004.

Hill, B., "Innovationsquelle Natur," Technische Universität München, 1997.

Kaiser, M. K., Hashemi Farzaneh, H., Lindemann, U., "An Approach to Support Searching for Biomimetic Solutions Based on System Characteristics and its Environmental Interactions", Proceedings of the International Design Conference – DESIGN 2012, Marjanovic D., Storga M., Pavkovic N., Bojcetic N. (Ed), Dubrovnik, Croatia 2012, pp. 969-978.

Kaiser, M. K., Hashemi Farzaneh, H., Lindemann, U., "BIOscrabble – Extraction of Biological Analogies out of Large Text Sources", IC3K 2013: 5th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management – SCITEPRESS Digital Library, Vilamoura, Algarve, Portugal, 2013, pp. 10-20.

Ke, J., Wallace, J. S., Chiu, I., Shu, L. H., "Supporting Biomimetic Design by Embedding Metadata in Natural-Language Corpora", Proceedings of the ASME 2010 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2010, Montreal, Quebec, Canada, 2010, pp. 1-8.

Löffler, S., "Anwenden bionischer Konstruktionsprinzipe in der Produktentwicklung", Technische Universität Carolo-Wilhelmina zu Braunschweig, 2008.

Nagel, J. K. S., Stone, R. B., "A Systematic Approach to Biologically-Inspired Engineering Design", Proceedings of the ASME 2011 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2011, Washington, DC, USA, 2011, pp. 1-12.

Nagel, J. K. S., Stone, R. B., McAdams, D. A., "An Engineering-to-Biology Thesaurus For Engineering Design", Proceedings of the ASME 2010 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2010, Montreal, Quebec, Canada, 2010, pp. 1-12.

Pahl, G., Beitz, W., Feldhusen, J., Grote, K. H., "Engineering Design: a Systematic Approach", Springer-Verlag, London, 2007.

Shu, L. H., "A natural-language approach to biomimetic design", Artificial Intelligence for Engineering Design, Analysis and Manufacturing, Vol. 24, No. 4, 2010, pp. 507-519.

Shu, L. H., "Generalizing the Biomimetic Design Process", Proceedings of CDEN/RCCI Inaugural Design Conference, Montreal, Quebec, Canada, 2004.

Stone, R. B., Wood, K. L., "Development of a Functional Basis for Design", Journal of Mechanical Design, Vol.122 (December), 2000, pp. 359-370.

Stroble, J. K., Stone, R. B., McAdams, D. A., Watkins, S. E., "An Engineering-to-Biology Thesaurus to Promote Better Collaboration, Creativity and Discovery", Proceedings of the 19th CIRP Design Conference – Competitive Design, 2009, pp. 30-31.

Vandevenne, D., Caicedo, J., Verhaegen, P.-A., Dewulf, S., Duflou, J. R., "Webcrawling for a Biological Strategy Corpus to Support Biologically-Inspired Design", CIRP Design 2012, Springer-Verlag, London, 2012, pp. 83-92.

Vandevenne, D., Verhaegen, P.-A., Dewulf, S., Duflou, J. R., "A Scalable Approach for the Integration of Large Knowledge Repositories in the Biologically-Inspired Design Process", International Conference on Engineering Design, ICED11, Boujut J.-F., Tomiyama T., Reich Y., Duffy A., Papalambros P., Copenhagen (Ed), Denmark, 2011.

Vattam, S. S., Goel, A. K., "Foraging for Inspiration: Understanding and Supporting the Online Information Seeking Practices of Biologically Inspired Designers", Proceedings of the ASME 2011 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2011, Washington, DC, USA, 2011, pp. 177-186.

Dipl.-Biol. Maria Katharina Kaiser, Research Assistant
Technische Universität München, Institute of Product Development
Boltzmannstr. 15, 85748 Garching, Germany
Telephone: +49 89 289 151 36
Telefax: +49 89 289 151 44
Email: kaiser@pe.mw.tum.de
URL: http://www.pe.mw.tum.de