BIOMIMICRY DESIGN TOOLING

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Abstract

The demand for a focus on nature-oriented design education and the improvement of 21st century teaching skills has grown exponentially in recent years. Biomimicry addresses these needs but the lack of scientific research on didactic methodologies leaves teachers and students utilizing examples with little knowledge on how to start efficiently within the design process. This research structurally assesses how biomimicry is currently taught and learned, which difficulties arise and which applications are most useful, so that effective educational strategies are developed, evaluated and implemented. This ultimately increases the number of successful sustainable, circular designs produced by multi-disciplinary student teams.

Keywords: Bio-inspired design / biomimetics, Ecodesign, Design education, Design learning, Biomimicry

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1 INTRODUCTION

"Biomimicry = From the Greek bios, life, and mimesis, imitation" (Benyus, c1997).
There is an urgent need for nature based design as the world around us is changing rapidly. Resources are being depleted and the planet is overflowing with waste. The world needs products to improve future generations, not degrade them. Natural forms, structures and systems can be used as a starting point for design solutions. This design approach is called biomimicry.
"Biomimicry is learning from, and then adapting Nature's best ideas to solving human technological challenges, in order to create a healthier, more sustainable planet" (The Biomimicry Institute, c2009).
The scope of biomimicry has been explored in depth by pioneer Janine Benyus in her book *Biomimicry - Innovation Inspired by Nature*, yet it does not explain the learning of this discipline as it was the written birth of biomimicry into the world.
On one hand, biomimicry has begun to spread in The Netherlands as well as around the globe. On the other hand, nature-driven designs didactics have not taken root to become mainstream yet. The purpose of this research is to examine preconditions and success factors of teaching and learning biomimicry through experimentation in current design courses and in multi-disciplined workshops. This practice encourages implementation of learnt principles within our education system, making biomimicry explicitly clear as an attractive design starting point.

2 SCOPE OF RESEARCH

The scope of this research examination takes place within 5 consecutive research phases over the period of a maximum of 5 years (2016-2021). The first two phases focus on how biomimicry is currently taught and learned. The third reviews characteristics and obstacles observed during teaching and learning. In the fourth phase, tools are tested to find clues on how to improve biomimicry educational processes. Based on these improved methods, the fifth phase compares found analogies and results in strategies in which students learn biomimicry more effectively. Through discovering methods that attract both students and teachers by integrating biology and nature with design and technological fields, biomimicry and other nature inspired design will be effectively applied.
"The challenge lies in whether we can innovate fast enough, which is necessary for realizing the transition. Innovators of this transformation must move to an approach where research, design and testing are integrated" (Valkenburg and Sluijs, c2012).
The results found during the pilot phase of this research will focus on: the internalization of biomimicry or rather the absorption and immersion, by students and clients at The Hague University together with Delft and Leiden Universities and Naturalis Biodiversity Center. The aim is to gain knowledge on the first steps needed to integrate biomimicry into a university Industrial Design Engineering program in The Netherlands. This knowledge justifies continuation of the research direction described below.

2.1 Scope of research: Biomimicry in The Netherlands

In 2013, BiomimicryNL created a roadmap 2020 initiating a biomimicry network within The Netherlands. Their website states (biomimicrynl.org) "although … advantages of using biomimicry have been proven in architecture, biology/chemistry, mechanical engineering, … and design, and although interest has grown in The Netherlands, there has been insufficient growth of teaching how to do so in higher education until recently" (translation Biomimicrynlorg, 2016).
This research aims to encourage growth within our education, attracting Top Sectors of our industries following the benchmark in Biomimicry NLs roadmap.
Because biomimicry is a new field in both design and engineering, major like-minded movements are explained here. The Biomimicry Institute "seeks sustainable solutions … by emulating nature's time-tested patterns and strategies" (Biomimicryorg, 2016) which is similar to *Bionica Innovatie en Expertise Centrums* definition found on bionicacentrum.nl. Nature Inspired Design (NID) at TU Delft aims "to develop products that enable circular business, … to create similar interdependent systems of products and their surroundings" (De pauw et al, 2015). Cradle to Cradle (C2C) or "waste equals food" dictates that materials in a design need to stay "within closed-loop industrial cycles, …" (Mcdonough and Braungart, c2002). A translation into Dutch was introduced to The Netherlands in 2007 by Anne-Marie Rakhorst. Biomimicry, Bionica, NID and Cradle to Cradle all follow similar paths aiming towards

implementing and inspiring a new sustainable design thinking. While these may explain facets of practicing biomimicry, there are few examples documented on how these are currently experienced in education.

2.1.1 Scope of research: Problem statement

To discover if there is an actual need for adapting the way biomimicry is now taught and learned, research on this subject found three issues outline existing problems: (1) educators and learners cannot find substantial research on effectiveness of these didactics; (2) biomimicry is expanding globally at an extremely rapid pace; and (3) clear communication is essential between different disciplines speaking different jargon.

1. Neither general educational materials nor design educational sources offer substantial research on effectivity of biomimicry methodologies. “Some famous biomimetic solutions have gotten passed around the mainstream press– … like self-cleaning surfaces modelled on lotus flowers, or the sticky repositionable tape inspired by gecko feet or wind turbines inspired by whale fins– but biomimicry isn’t as easy as using nature as a crib sheet.” (Mckosky, c2012). Ingrid de Pauw and others at TU Delft in The Netherlands, compare biomimicry to other sustainable design methods in *a case study of student design projects, Comparing Biomimicry and Cradle to Cradle with Ecodesign*, and mention this scarcity in research. Examples are limited (De pauw et al, 2014).
2. Global momentum in the world of biomimicry validates that the time has come to reflect on the effectivity of what is being done. These organizations recently reached out to designers, teachers and interested ecologists and naturalists to offer instruction. No research can be found on the effectiveness of these instructions. For example, Biomimicry NLs Roadmap 2020 was completed in 2013 and in 2015, Ylva Poelman, became the first “Lector Biomimicry”, published the first Dutch book on *Bionica*, and began bi-weekly columns in *Trouw*. The Biomimicry Institute has offered information since 2015 within a global network, and while Biomimicry 3.8 has been active since 1998, the program co-founders Janine Benyus and Dayna Baumeister, experience exponential growth only recently. By linking up with Arizona State University (ASU), Biomimicry 3.8 celebrated their first cohort of graduates with a MSc in Biomimicry (Biomimicrynet, 2016) in 2016. Because this program is so young, substantial research is not yet published on this education.
3. Designers learning and communication methods may differ from other fields. A designer must effectively learn how to communicate with non-designers and will often do this visually, linking analogies (visualizations and practical models) to this research. At the same time, a clear communication between teachers of biomimicry and management level decision makers is essential. This research aims to bring clarity to this necessity.

2.2 Scope of research: Research questions

Main research question: Which methods of biomimicry teaching can be effectively integrated into an existing design program leading towards a more efficient and ecologically motivated design process, and in particular how can analogical thinking be used to enhance this?

By answering these questions in peer reviewed scientific articles, and implementing results directly into education, this research will increase sustainability within our design engineering education. Where the entire research aims to cover all 4 research questions, the pilot phase aims to discover the first hunches of where we might look (the itch).

RQ1: How is biomimicry currently introduced and taught at university levels and which tools and methods are used to increase focus on responsible design? Which obstacles exist?

RQ2: How is biomimicry currently learned and how can effective learning be measured and documented? Which obstacles exist?

RQ3: Which aspects of a biomimicry design lesson are effective? What are the most preferred and effective moments in the internalization learning process by decision makers, teachers and students?

RQ4: What assumptions can be made through comparative analyzation concerning positive biomimicry learning? After testing, results are reflected and new insights can be identified to mark positive introduction methods so that these will be implemented into our design education.

2.2.1 Scope of research: methodology per phase

During each phase of research, methods will be evaluated in a trustworthy manner. Population, target group or case study sample size will be described in detail and its implications on results will be evaluated.

4. RQ/Phase 1 and 2 focus on examples of showcase implementation, teaching and learning using qualitative inquiry research via observations, interviews and documents at Arizona State University (ASU and Biomimicry 3.8) Master of Science in Biomimicry program. The aim is to assess which characteristics are key in this USA based program and to compare these to programs in The Netherlands (including biomimicry lessons I teach) as compared to ASU/BMY3.8. Interviews will be conducted with Biomimics and ASU alumni around the globe to find other key aspects which might prove useful as teaching and learning tools. The focus during RQ2 is on how students store and retrieve knowledge. Case studies, conversations and brainstorming results are gathered, defined and analysed on learning methods. Do students know why they are learning this and how does this knowledge help internalization of the subject? In online classrooms, personal observational data is collected followed by comparative and conversation analysis (where possible) to collect data to understand current knowledge storage and retrieval. Daugherty and Mentzer (2008) validate this need, adding that "Understanding how engineering designers store and retrieve knowledge during the design process can be particularly beneficial to informing technology education". Conclusions on the internalization to this learning will be formed here.
5. RQ/Phase 3 focusses on successes and analogies: research methods used are quantitative research, open ended coding and qualitative Stimulated Recall (SR) methods. Earlier session results will be used to systematically test results (3-5 students/group, 5 groups, 4x/year) at The Hague University. To focus on major issues, there should be a maximum of 3 specific theories examined. By systematically observing and questioning students after recorded workshops, aspects which stayed in their memory (using stimulated recall) can be found. Do teachers recognize difficulties found in RQ3? What kind of analogies were used for structure, form and function? Have these been used correctly? It is important to discover if what teachers believe is taught, is actually learned. With Stimulated recall (SR), participants repeat their perceived learnings. Lyle (c2003) describes SR as a documented process where participants are asked what they were thinking after watching a recording of that event.

   A study on analogical transfer in biologically inspired design, should also be considered during this forth phase. In 2006, a study at Georgia Institute of Technology focused on this. Swaroop et al (2006) noticed that solution-driven processes were driven by the initial source while a problem driven process focused on that source (e.g. form), limiting the diversity of design ideation. This study found that designers "consistently fell prey to a common set of mistakes" (Swaroop, et al, 2006). Helping students recognize analogies and discovering if these are a major obstruction in teaching/learning biomimicry, gives a unique focus to this research. These utilized analogies will be tested, considering "the ability to pick out patterns, to identify recurrences of these patterns … to form concepts that abstract and reify these patterns, and to express these concepts in language" (Holoyoak et al, 2001). This finalizes systematic testing and prepares for the intervention phase.
6. RQ/Phase 4 focusses on implementing best practices: research methods used are qualitative research method - comparative analyzation (constant comparison). This final phase of research is for implementing successful methods of implementation at all levels. Have elements been found to increase internalization within a school or to prove that analogies e.g. can help? Do students recognize how to implement form, function or systems e.g. effectively? Here, implementation of "Best practices" takes place in the new situation. The main focus is to gather and cluster data during planned workshop sessions implementing sequential improvement sets. This will enable implementation of best practices in a larger group (in a program curriculum).

3 THEORETICAL FRAMEWORK

Research on biomimicry should use two essential, guiding methodologies: Active Learning and Inquiry-based research, integrated into a Design Research Methodology (DRM). These methodologies aim to build within the framework of current Industrial Design Engineering (IDE) methods which are based on the *Delft Design Guide.*

The IDE program at The Hague University actively encourages students to take charge, designing his/her own education, so to speak. Active learning theories of Von Glaserfeld's (1993) constructivism are quoted by Karagiorgi and Symeou (2005) where "the centre of instruction is the learner. Meaningful understanding occurs when students develop effective ways to resolve problematic situations... Constructivists recommend that designers provide problems which may be solved in different ways and leave students struggle with problems of their own choice" (von Glasersfeld, 1993; Karagiorgi and Symeou 2005).
Also at IDE, our students and teachers are included in reflective evaluation processes. "Inquiry-based research conducted by teachers that follows a process of examining existing practices, implementing new practices, and evaluating results, leading to an improvement cycle that benefits both students and teachers" (Hudacuk, 2016).
DRM, a Design Research Methodology, as Blessing and Chakrabarti described, will incorporate these active, reflective research processes into the research question phases as follows:
"[D]esign research not only aims at understanding, but also at improving design. This requires (1) a model or theory of existing situations [which will be carried out in Research Q1,2 &3], (2) a vision (model or theory) of desired situations [Research Q4], and (3) a vision of support that is likely to change the existing situation into the desired situation, and maintain this [Research Q5]… illustrate[ing] the overall aim and objectives, and highlights the facets of design..." (Blessing and Chakrabarti,c2009).
Using a qualitative approach, models of existing situations at ASU (as expert) and THUAS (as developing university) will be compared. The vision of the desired, improved situation will be formed through the analysis of these models and the results from the testing phase into a "best practices model". To reach this vision, active learning – with myself as a teacher/student on one hand and current students involved at ASU and Dutch universities on the other hand, will be analyzed through this inquiry-based research plan. The introduction of the more science-oriented field of biology into a design-oriented field is facilitated by this active and inquiry based approach.
A Pakistan's study by Akhter and Husain, illustrates the understanding that science cultivates curiosity and "science literate thinking" in teachers, giving them confidence facilitating the learning process. Their definition of such learning fits perfectly in this research as both the ASU Biomimicry and THUAS' IDE program encourage this: "A way of teaching that helps students achieving understanding in science by combining scientific knowledge with reasoning and thinking skills. The role of the teacher is to act more as a facilitator of learning than as a sole instructor" (Akhter and Husain butt, 2012).

4 LITERATURE REVIEW

Key words: Biomimicry, Design Engineering Education, EcoDesign, Sustainability, visual analogies.
Research question: Which methods of biomimicry teaching can be effectively integrated into an existing design program leading towards a more efficient and ecologically motivated design process, and in particular how can analogical thinking be used to enhance this? The importance of how to internalize
By questioning and examining how is it taught now, a first assessment can be made as to what helps students internalize biomimicry into their regular design thinking processes. How do students/teachers recognize the need for biomimicry and do they recognize the possibilities that these principles offer? How do students understand what steps are required to learn and what not to focus on?
The literature found on biomimicry and design education can be divided into four categories:

- Informative biomimicry websites offering education and consultation (incl. MSc programs);
- Research, specifically on visual analogy values in the transfer of biologically inspired design;
- Research articles on using biomimicry within science and compared via specific scientific fields;
- Research articles/books on biomimicry and practices of sustainable design methodologies;

4.1 Literature review: Educational and consulting websites on biomimicry

Biomimicry.net is the doorway to the globally expanded website from co-founders Benyus and Baumeister. Once called the Biomimicry Guild and now named Biomimicry 3.8, this website is a gateway linking many of the global biomimicry experts. The emphasis is on cooperative learning and the websites have recently become more engaging and similar, while maintaining a personal brand image to reach alternative target groups.
Biomimicry 3.8 found its origin in 1997 when Janine Benyus and Dayna Baumeister founded the Guild, which later became 3.8 (after 3.8 billion years of evolution).

Biomimicry design engineering education, provided by Biomimicry 3.8 and their co-partner Arizona State University (ASU), looks at natural forms, structures and systems and use these as a starting point for design solutions. The Biomimicry Resource Handbook is a collection of charts and best practices to help beginning biomimics get started. The websites and handbook educate, inspire and offer examples of innovation. It does not research into how we teach or learn biomimicry.
The Arizona State University (ASU) Master of Science Biomimicry course uses textbooks and research papers such as the Biomimicry Resource Handbook (2014).
By following the courses at ASU, examining how Dutch University are starting to incorporate biomimicry and through scientific articles on biomimicry, education on specific aspects of biomimicry can be examined, but these do not (yet) offer research on how we teach or learn biomimicry.

4.2 Literature review: Analogical values in biologically inspired design

Analogical reasoning is a function of the associative, similarity-based reasoning system, where problems are reasoned about through associations or similarities with other known information (Daugherty, J., and Mentzer, N. 2008). These articles offer insights into learning and communication between fields. During this research, the two basic forms of analogical reasoning, understanding the operation of a device, and problem solving (Daugherty, J., and Mentzer, N. 2008), may indeed make the design process more visual. These two basic forms of analogical reasoning (understanding the operation of a device and problem solving) are also commonly found in the technology education classroom, although they may not be made explicit to the students (Daugherty, J., and Mentzer, N. 2008). This study aims to record, test and recognize where visuals are more effective, so that biomimicry design teachers may use these analogies more effectively as well.

4.3 Literature review: Teaching science and biomimicry within specific fields

The thesis paper Graphic Design and Biomimicry by Margaret McKosky, examines how biomimicry can positively influence the field of graphic design. While this also uses case studies and looks at tools, it does not look at how biomimicry is taught or learned.
“As with any creative process, it requires practice for it to become second nature. This new Graphic Design + Biomimicry process I am proposing is meant to challenge the current paradigms and create the potential for change.” (Mckosky, c2012) In this sense only, creating the potential for change is similar.
Perhaps the field which has incorporated biomimicry the most is architecture. The book Biomimicry in Architecture by Michael Pawlyn, “looks to the natural world to seek clues as to how we can achieve radical increases in resource efficiency” (Pawlyn, c2011) and demonstrates concepts and realized projects.
Gardner explains in his Using Biomimicry to Engage Students in a Design-Based Learning Activity on the web forum The American Biology Teacher, how biology teachers can include biomimicry in their lessons. (Gardner, c2012) This paper is geared more towards High School biology classrooms and explains similar steps as the basic course biomimicry 3.8 offers, yet it does not analyze how is taught and how this is learned. This paper compares the Design Based Learning and how this has a natural fit with the Science of teaching Biomimicry, showing a parallel between the two, while stating that a more circular system exists within biomimicry. Again, the steps are mimicked while in depth research on the how and why is nonexistent. The emphasis is on biology.
Teaching science effectively is analysed in Temi Teaching and is used by University Leiden in The Netherlands. How using Mysteries supports Science Learning and The Book of Science Mysteries are two books written by the TEMI team and use teaching methodologies following a 5E system (Engage, Explore, Explain, Extend and Evaluate), complete with worksheets for science teachers. During this project on Biomimicry Design Tooling, comparisons can be made between these teaching methods to what is currently used in biomimicry.

4.4 Literature review: Biomimicry and comparing sustainable design methodologies

Janine Benyus is the founder of the term Biomimicry and author of Biomimicry: Innovation Inspired by Nature. “Benyus has worked since then to popularize and organize ad hoc biomimetic practices that are probably as old as human invention (Bloombergcom, 2016). This book inspires and explains the basics of what Biomimicry is, but does not expand on teaching or learning.

The book Nature Inspired Design (De pauw et al, 2015) has incorporated most of the biomimicry methods into case projects to illustrate how this can be implemented. "Three cradle to cradle Design Principles and six biomimicry Life's Principles largely overlap and we have merged them into one set of NID Principles, a set of six" (De pauw et al, 2015). However, there is not a wide scale teaching method as Biomimicry now has on an international scale reaching around the globe.
The Cradle to Cradle (C2C) 'waste equals food' principle brought about a mindset change in the Netherlands in 2007 when the book (and the theory that goes alongside) was translated into Dutch and presented to the country by Anne-Marie Rakhorst of SEARCH. C2C rethinks the way we make things by taking care that materials used enter a "closed-loop industrial cycle" (Mcdonough and Braungart, c2002).
While these principles were introduced to Dutch universities almost 10 years ago, they could be strengthened by moving beyond the materials and manufacturing by combining these with the principles of biomimicry at the start of the design process to add form, function, patterns, systems and structures.
The Dutch book "De Natuur als uitvinder" (nature as inventor) by Ylva Poelman has been published at the same moment that she announced her 'shared lectureship at the HAS Hogeschool, Hogeschool Van Hall Larenstein, Stoas Hogeschool and Hogeschool Inholland' (own translation - HAS hogeschool, 2015). The illustrations and examples of biomimicry are called bionics here and are similar to the examples given by Biomimicry 3.8 and the website ASKNature, but differ in respect towards the gratitude and love for nature that the former radiate. Bionics appears to be more pragmatic in its approach and is not specifically looking for what it can also give back to nature. Although many examples are given, a book remains a limited set. These may be used as examples, but are not learning tools in themselves (Poelman, c2015).
Biomimetics for Architecture and Design by Göran Pohl and Werner Nachtigall aims to help architects to grasp the fundamentals of mimicking nature through observations and examples, thus helping to grasp the "analogous structures" establishing the "functional similarity" after observations of these examples (Pohl and Nachtigall, c2015). Both books explain methodology, steps as well as beautiful examples of structures. Neither books do research into the teaching or learning of biomimicry itself.

4.5 Literature review: What is missing?

While initial searches for literature on research on educating the subject left the reader empty handed, there has been an explosion of new books and research articles on these related subjects between March and December, 2016. The major US (founding) websites have received facelifts and have begun to collaborate even more than a year ago. These have also reached out to collaborate with biomimicry professionals who have recently graduated from the founding courses and first cohort of ASU's MSc in Biomimicry, many of whom have recently updated their own websites and have written journal articles on the subject. In the US, a strong link exists between knowledge data bases, the Masters education and professional courses of Biomimicry 3.8. Research on teaching basic science classes show similar values as these initial founders and a similar connection can be made to "The Big 5 of Education" according to Naturalis Biodiversity Center in The Netherlands. It is already clear that effective teaching of biomimicry should also fit these five priority values: amazement, real, relevant, investigative and scientific (translated from Priority checklist Naturalis Biodiversity Center, 2015).
While each of the literature examples found gives profession specific examples, there remain very few examples directed towards research on teaching and learning biomimicry. This is therefore the focus of this project.

5 CONCLUSION

The aim of the first paper is to look at the initial internalization of biomimicry by both teachers and students in the design field, working together in multi-disciplined teams. Through examining the current theories and methods of how biomimicry is currently taught and experienced by all named parties, conclusions may be drawn about insights into initial internalization in current programs both in The Netherlands as around the world.
Results will be presented for peer assessment to assess and make a first hypothesis of how decision makers, instructors and their students are internalizing and absorbing knowledge on biomimicry. This paper is also to propose a re-evaluation of these steps together with participants from Dutch universities who took part in the Global Conference on Biomimicry and Bio-Inspired Innovation in Utrecht, NL in

November 2016. I intend to ask for their collaboration to receive feedback and input from their experiences. In addition, I have received a doctoral grant to do this research, enabling a starting date of December 1st, 2016.

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