INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'09
24 - 27 AUGUST 2009, STANFORD UNIVERSITY, STANFORD, CA, USA

BIOMIMETICS AS A DESIGN METHODOLOGY – POSSIBILITIES AND CHALLENGES

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ABSTRACT
Biomimetics – or bionik as it is called in parts of Europe – offer a number of promising opportunities and challenges for the designer. The paper investigates how biomimetics as a design methodology is used in engineering design by looking at examples of biological searches and highlight the possibilities and challenges. Biomimetics for engineering design is explored through an experiment involving 12 design engineering students. For 7 selected problem areas they searched biology literature available at a university library and identified a number of biological solutions. Central solution principles were formulated and used for designing technical items that could be used to solve the initial problems. Experiences are that biomimetic design can be made successfully using commonly available biological literature and internet resources and that designers without detailed biological knowledge can perform biomimetic design at a conceptual level. However often more detailed understanding of the biological and in particular the biochemical phenomena is required. This could be achieved through collaboration with biologists.

Keywords: Biomimetics, bionik, design methodology, inspiration, functional principles.

1 INTRODUCTION
Biomimetics - or bionik as parts of Europe calls it – is the discipline of creating new objects with inspiration from nature. The terms are constructed from Greek “bios” meaning life, the suffix “ik” from ‘mechanik’ (meaning mechanics in German) and “mimeistai” meaning imitate. There are excellent books on biomimetics highlighting both its history, its coupling to human ecology and many interesting examples [1, 2, 3, 4, 5]. The discipline is interesting for designers since it offers a huge base of well proven design principles – many of them have evolved over millions of years and proven their value by still being in use. The inspiration from nature can be direct and remind of copying or it can be more indirect where phenomena or principles found in nature are used more freely within the design process. Inspiration from nature has been done for many years, but biomimetics as a scientific discipline is still in its infancy. It is straight forward to do biomimetic design when a direct analogy to the actual design situation is apparent. For example it was probably an easy deduction for the stone age man to make clothes from animal fur – he could see that the animals could withstand the cold weather. However, the amount of inspiration available in nature is much larger than the direct analogies. Many of the underlying principles that explain the functionally in animals and plants are not immediately recognisable and a more advanced study is required to find and understand them. Biomimetics as a scientific discipline needs to formulate theories that will explain the relations between nature and technology and develop methodologies that will facilitate the design process.
Design is basically about creating new ideas and transforming them into physical or immaterial concepts. But the design activity will be different depending on the focus. Engineering design with focus on mechanics and industrial design with focus on aesthetics use biomimetics in two fundamentally different ways [6]. Roughly speaking the engineering designer are mostly focused on inspiration to new functional principles, like for example cleaning principles or principles for reduced flow resistance. The industrial designer on the other hand has focus on inspiration for aesthetics and geometric shape, like plant shapes and animal expressions. This is of course a very rough generalisation and the real world picture is much more complex. Furthermore will both groups also be interested in other aspects of nature, for instance system oriented inspiration from ecosystems. But the distinction is important when looking at supportive measures for biomimetics. Search methodologies for mechanical principles are very different from retrieval tools for geometry and shape.

2 BIOMIMETICS FOR ENGINEERING DESIGN

Using biomimetics for engineering design involves a number of steps as illustrated in figure 1. The steps are 1) a search for relevant analogies, 2) a proper analysis of the biological solutions, 3) interpretation and identification of design principles and, 4) design of the desired artifact [7, 8]. The search most often requires refinement activities where the search area is widened as well as focused.

Basically a biomimetic search can be done using different sources of biological information. The biomimetic group at University of Toronto [7] uses a biology text in computer-searchable format, a digital version of the standard university biological textbook "Life, The Science of Biology" [9]. Text strings used in searches are functional keywords, to increase the chances of finding deep, rather than superficial analogies that contain functional similarities. This is an excellent source, but it has three limitations. One is that researchers and designers without the online access can not use it. Another is that although the amount of knowledge in the biology book is large it does not include the findings from recent biology research. A third limitation is the terminology – the book is written to biology students and can be difficult to understand for people without basic biology knowledge.

Another source obvious to researchers is the scientific literature in the form of books and journal papers. Within the last years this has become even easier since on-line searches can be accessed through most University libraries. The experiment described in this paper uses this source which overcomes the first two limitations mentioned above.

The Toronto group point at a significant challenge in the search phase, namely the translation between engineering keywords and biological equivalents. Their work seeks to overcome this challenge using natural language analysis and a method for generating biologically meaningful keywords from engineering keyword terms described in the Functional Basis [10, 11].

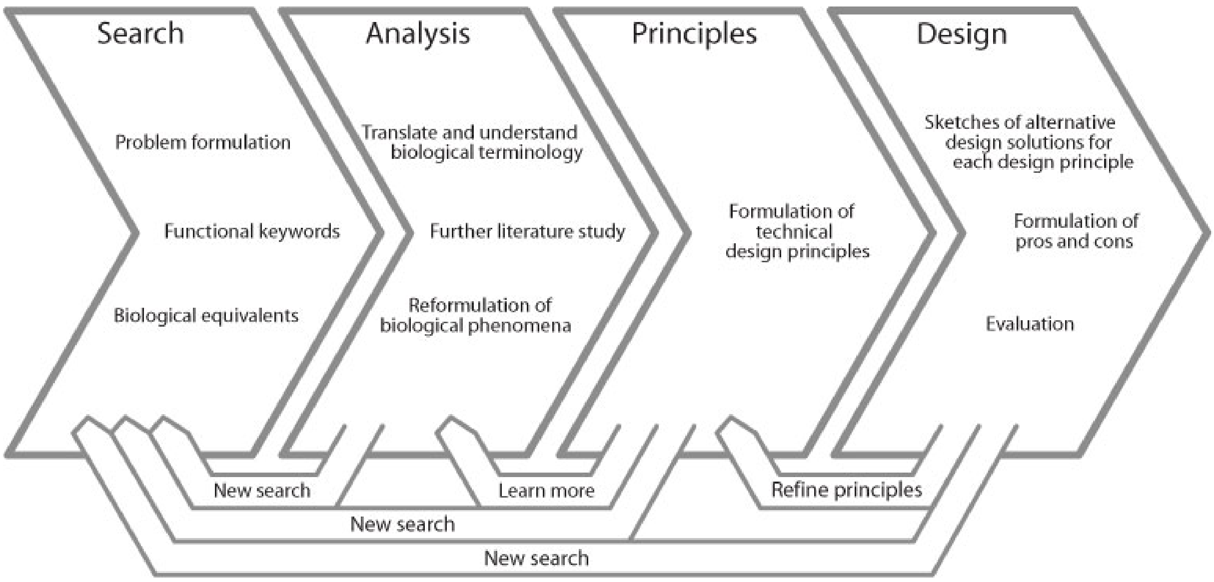

Figure 1. Biomimetic design methodology

3. THE EXPERIMENT

An experiment has been set up to explore the usefulness of the biomimetic method for engineering design using commonly accessible biological literature. The experiment involved 12 engineering design students in their final 4th or 5th year. The students were familiar with design methodology and have extensive experience with product development projects. Their motivation for participating in the experiment was apart from course credit a desire to get acquainted with the huge solution space that nature represents.

The experiment was structured in the following steps: introduction, problem area, biological search, interpretation and design.

3.1 Introduction

The introduction comprised examples of previous biomimetics work and description of some of the success histories like the Velcro, the self-cleaning lotus flower and hydrodynamic shark skin. Attention was drawn to the search methodology shown in figure 1 and to the importance of using the functional need in the problem area when searching the biology domain.

3.2 Problem area

To mimic a normal design situation and at the same time ensure the continued motivation for the participants, a number of problem areas were identified through a brain storming session. The brain storming was carried out using A0-size of white paper where the participants wrote down areas from our daily life that they thought needed improvement. This was done in groups of 2-3, and after 10-15 minutes the papers were passed to another group which continued the work. The papers were placed on the wall and 'in plenum' a short list of the 18 most important areas was selected. Examples of the areas were 'storage of food', 'cleaning' and 'water cleaning'. Each participant chose one area for the continued work. After one days work the interim search results were evaluated 'in plenum' based on their potential and on the ease of exploring the area. Some topics required a more detailed biochemical understanding and were deselected. The resulting 7 problem areas are shown in table 1.

*Table 1. Selected problem areas and primary search words. A * (asterisk) in the word find more versions of the word, e.g. sens* searches both sense and sensing.*

	Problem area	**Search words**
1.	Energy efficient movement on water (walk on water)	Locomotion, movement, water running, biomechanics, water surface
2.	Energy efficient movement in rugged terrain	Locomotion, energy, efficiency
3.	Mechanical energy storage, short duration high impact energy in/output <-> long lasting low impact energy in/output	Locomotion, energy, storage
4.	Navigation	Navigation, orientation, positioning, migration
5.	Active lumination in darkness	Light, (bio)luminescence, glow, emit
6.	Detection of victims in catastrophes	Detection, sens*, signal*, perception, sensation
7.	Prevention of personal attack	Defence, evasive behaviour, antipredator, prey, predator

3.3 Biological search

For each of the problem areas listed in table 1 a biological search was carried out over a period of 4 days. The place was a library at a university with a significant biological department. This gave access to a comprehensive amount of biological literature in paper form and online access to many of the important biological bibliographic databases and online journals.

One of the first challenges was the identification of suitable biological keywords. Different approaches were pursued. One was to search the biology books and the internet for central keywords to explore if significant amounts of relevant results could be found.

Table 2. search strategy example 'walk on water'

animals		water interface		locomotion
or basilisk lizard		or water surface		or movement
or basiliscus plumifrons	and	or water running	and	or running
or basiliscus basiliscus				or biomechanics
or basiliscus vittatus				
or jesus lizard				

For example for problem area 1 the initial search was "animal" combined with "movement", "water surface", "swimming" and "efficiency" and it did not induce any yield. A google search pointed at wikipedia [12] and an article on the Basilisk lizard. Here the right biological search words were found: Animal locomotion on the surface layer of water. Another approach was to define a search strategy by selecting significant keywords (that seamed likely to result in search results) and find a number of synonyms for each one. These were used in a logical ‘and’ and ‘or’ search like illustrated in table 2 and 3 to search scientific journals. In both cases significant amounts of relevant search results were found. Additional search strategies included identification of central authors and research groups when interesting biological phenomena were identified. Reference lists in books and journals were also very helpful.

Table 3. search strategy example ‘Energy efficient movement in rugged terrain’

and	Movement	Energy	Efficiency	Velocity	Terrain
or	Motion	Energetics	Effectiv*	Speed	Surface
	Locomotion	Energ*	Reduct*	Pace	Terrestri*
	Biomechanics	Power	Efficien*	Rate	Ground
	Kinematics				Country
	Move*				
	Glid*				
	Wind*				
	Walk*				
	Run*				
	Gallop*				
	Trot*				
	Crawl*				
	Sprawl*				
	Tint*				
	Roll*				

An interesting finding was that the increasing amounts of videos available on the internet at places like Youtube [13] offered a valuable supplement to many of the written sources found at the library. This is especially the case for the dynamic phenomena that are much easier to comprehend when seen ‘in action’.
Books were found using the normal library search system and by browsing the shelves around an interesting book. Journal papers were identified with the help of bibliographic databases like Biosis Previews [14] and Zoological record [15]. They distinguish themselves on the quality of the information since all papers listed in the databases are peer reviewed. However good results are also found in other sources like wikipedia [12], google scolar [16], more general google searches [17] and youtube [13]. The evaluation of the knowledge quality is here left to the reader, since only limited quality assurance is applied in those sources. Biosis Previews [14], Zoological record [15] and the library search system [18] only searches the title, author and abstract sections of the articles while google scolar [16], google [17] and Jstor [19] use full text searches.

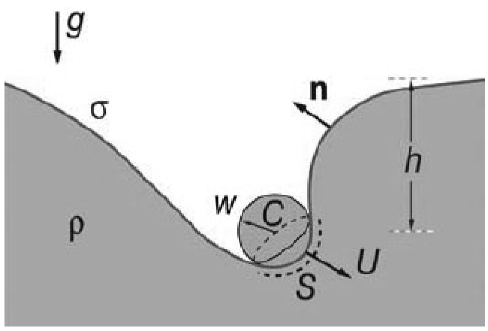

Figure 2. Basilisk Lizard [13, photo C. Horwitz] and the forces acting on the driving leg [22]

To illustrate how the biological search was carried out we can look at the work done for the first problem 'Energy efficient movement on water (walk on water)'. A number of animals and insects capable of walking on water were identified in 2 books describing the motion of various animals [20, 21] using the search words 'animal locomotion' in [18]. When 'water' was added to the search string no results was found. The interest in the area was not only the dream of walking on water, but a desire to find more energy efficient principle for water traffic. It was assumed that more energy efficient motion were possible when the creatures did not break the water surface. The basilisk lizard (figure 2) was selected for further study since it weights up to 200 grams and is much larger than the insects. Good literature were fairly quickly identified through Biosis [14], Zoologial records [15] and Google scolar [16].

To illustrate the differences between the various search sources a small test was made. Different search strings were formulated and used in a range of the sources as shown in table 4.

Apart from simple search strings 2 more complex combined search strings were used .The one more complex search word combination SWC1 was

- (Animals OR Basilisk lizard OR Basiliscus plumifrons OR Basiliscus basiliscus OR Basiliscus vittatus OR Jesus lizard) AND ("Water interface" OR "water surface" OR "water running") AND (Locomotion OR movement OR running OR biomechanics).

The other more complex search word combination SWC2 was

- (Basilisk lizard) AND ("Water interface" OR "water surface" OR "water running") AND (Locomotion OR movement OR running OR biomechanics).

To evaluate the relevance of the search results the first 10 results were examined and evaluated as either not relevant (marked red in table 4), of some relevance (marked yellow in table 4) and highly relevant (marked green in table 4).

The test shows that some of the simple search string could deliver fair results – in particular when the name of the animal was known. However the more complex search strings were able to encircle detailed knowledge on the topic. So it is worth the effort to use the time and be careful in formulating good search strategies.

Table 4. Statistics for search for problem area 1. Colour code based on first 10 hits: red: not relevant, yellow: some relevance, green: highly relevant .

Search term	Google [17]	Google scollar [16]	Library search system [18]	Bibliographic database BIOSIS [14]	Bibliographic database Zoological records [15]	JStor [19] – full text search
"Walk on water"	1.450.000	2.080	1	463	645	18
Lizard	26.600.000	116.000	38	497	795	868
Basilisk lizard	53.700	2.640	0	333	803	137
Jesus lizard	2.000.000	7.050	0	326	797	448
"Jesus lizard"	403.000	39	0	326	797	1
SWC2	1370	168	0	198	58	21
SWC1	94	15	0	7	14	Search string to long

Table 5 list many of the findings from the searches on the 7 problem areas. The left column describes biological phenomena that solves the problem area in question. As it can be seen was it possible to identify many different relevant biological phenomena even though the search was focused on the macro level, i.e. animals and plants and their overall behaviour. The right column describes how the biological phenomena work. In many cases the principles explaining the phenomena were available in the literature but it was more difficult to find quantitative data. For example is the light producing mechanism in fireflies and bacteria well explained but data on the light intensity is very scarce. The reason is that biologists are focused on the biological behaviour. For biologists is the relevant information that the light specs can be seen of fireflies of the other sex – not necessarily a measure-

Table 5. Examples on biological solutions for the 7 problem areas.

	Examples of biological phenomena	Behavior or biological function
1.	• Lizards • Water strider • Fisher spiders • Swimmers, e.g. penguins with reduced water resistance • Sharks with reduced water resistance	• The lizard runs on two legs on the water surface by continually and quickly striking the water surface with the hind legs in order to escape predators • Water striders and fisher spiders stay on top of the water surface thanks to the surface tension allowing them to live and hunt on water • Swimmers use hydrophobic surfaces to reduce drag • Sharks have small scales that reduces drag
2.	• Jump, e.g. kangaroos • two-legged walk/running, • four-legged walk/trot/gallop, • crawling, sprawling, • gliding, • wheels (golden wheel spider)	• Energy efficiency of land transport depends on the roughness of the surface and on the purpose of movement: Hunting/escape or migration, and on the manoeuvrability. • Walking or jumping on two or more legs is often the most energy efficient way motion on rugged terrain. • Kangaroos jumping are very energy efficient at fast speeds.
3.	• Cuticle and resilin in insects, • resonance and eigenfrequency in insects and lizards, • catapult mechanism in fleas and grasshoppers • mousetrap mechanism in trap jaw ants, • prestressing mechanism in guinea fowl birds, • kangaroos	• Many animals need to make a sudden attack or escape and therefore store mechanical energy that allow them to move quickly for a short distance. • When prey is fast there is a need for a fast catching mechanism like the ant with trap jaws • High frequency wing strokes in insects rely on a resonance mechanism • Efficient locomotion often store energy in tendons and muscles
4.	• Magnetotactic bacteria, • migrating birds (e.g. a Robin) and turtles can be magnetosensitive, • many insects senses polarized light in the sky	• Both bacteria, turtles and birds can travel in the right direction over large distances using the earth magnetic field inclination (vertical angle) • Insects use polarized sky patterns to follow a path
5.	• Anglerfish with head lamp (glow) • Bacteria that glow (long term) • Fireflies (flash) • Glowing mushrooms, shrimps, shellfish, squids and jellyfish	• The anglerfish uses its lamp to attract prey • Cypridina Hilgendorfii glow when disturbed • Fireflies use light for sexual attraction • Scrimps glow when disturbed • Squids glow when threatened
6.	All senses are used for location in some animal. Focus on smell. • Bloodhound • Silkmoth is very sensitive to a single particular molecule	• Dog use their olfactory sense for detecting prey • Silkmoths uses smell / pheromones for sexual attraction
7.	• Crypsis (avoid observasion): Snakeneck turtle, Crap spider • Physological defence (armour): Armadillo and Rhinoceros • Aposematism (warning colouration): Dart frog • Counterattack: Skunk, Bombardier • Confusion: Octopus / squid • Group call warning: Prairie dog	• Snakeneck turtles use algae as camouflage • Crap spiders look very similar to the plants they live on • The yellow / black colours of the dart frog signals that it is poisonous • Skunks excrete odours as a defensive weapon and bombardier beetles shoot boiling liquid • Octopus eject a smelly dark ink to confuse predators

ment of the light intensity. More important for the biologist is the spectrum of the light since it can be used to differentiate between different species.

3.4 Interpretation

Based on the understanding of the biological phenomena achieved in the analysis the next step was to interpret the phenomena and formulate the design principles. The principles should be formulated in an abstract way in order to stimulate the generation of design concepts.

Figure 3 Water strider Gerris remigis [13,Photo Markus Gayda]

Problem area 1

For problem area 1 “Energy efficient movement on water (walk on water)” 2 principles were found for staying on top of water and another 2 for reducing water flow resistance when swimming at the water surface.

- For very light structures like the water strider (figure 3) a principle that prevent braking the water surface is to use a strongly hydrophobic surface to prevent wetting and thus utilizing surface tension forces. Details on the mechanics is described by [23].
- More heavy structures like the basilisk lizard can use the surface tension forces in a clever way to generate lift and trust by first striking the water surface with the foot and then strike the foot downward with an elliptical motion to create an air pocket around it, and then pull it out of the water.
- Ducks have reduced drag when swimming at the water surface due to a multiscale structure and a hydrophobic surface. The hydrophobic surface is not wetted and can be achieved by coating the surface with wax. Small scales in the surface where the troughs between the scales are so small that they prevent wetting also add to the reduced drag.

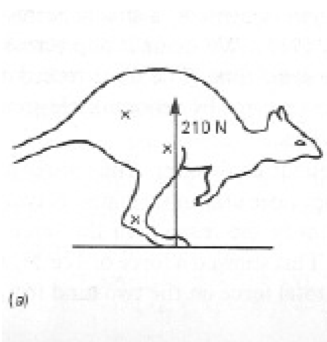

Figure 4. A jumping kangaroo can be more energy efficient than other forms of 2 and 4 legged animals.

Problem area 2

In problem area 2 “Energy efficient movement in rugged terrain“ a central element is the temporary storage of energy in the motion, i.e. the conversion between kinematic and potential energy. The principle in walking on two legs could be formulated as follows. One leg is lifted and while the body tilts forward, the leg is moved forward. The leg is lowered and when encountering the surface the energy is stored by stretching the tendons. The other leg is now lifted and the energy in the tendons are used to move the body forward and lift the first leg. However the efficiency of energy storage is very

different in different animals. Jumping kangaroos can store a high fraction of the motion energy in their tendons. At speeds from 5-15 m/s kangaroo jumping is more energy efficient compared to other forms of 2 and 4 legged walking and running [24].
Apart from this spring-like principle a pendulum principle is used in walking to reuse energy.

Problem area 3

Problem area 3 was “Mechanical energy storage, short duration high impact energy in/output <-> long lasting low impact energy in/output“. Also here a central element is the conversion of kinematic and potential energy. For the flea the trick is to prestress an elastic material that quickly can deliver the energy for the jump (figure 5). The principle in the mechanism is that the lower part of the leg is moved to the front most position towards a physical stop. An elastic material (a tendon) is pulled strongly like a rubber band. The elastic material is moved backwards whereby it passes the centre for rotation causing the lower part of the leg to flip very quickly backwards.
Certain lizards and many insects make use of resonance to save energy. The 2 legged Bipedalus physiciensis elegans use its spine to store energy as oscillation [25] similar to the way a child keep a robe swing moving (figure 5). The trick is to use a mechanism with the right eigenfrequency where a minimum of energy is needed to keep it swinging.

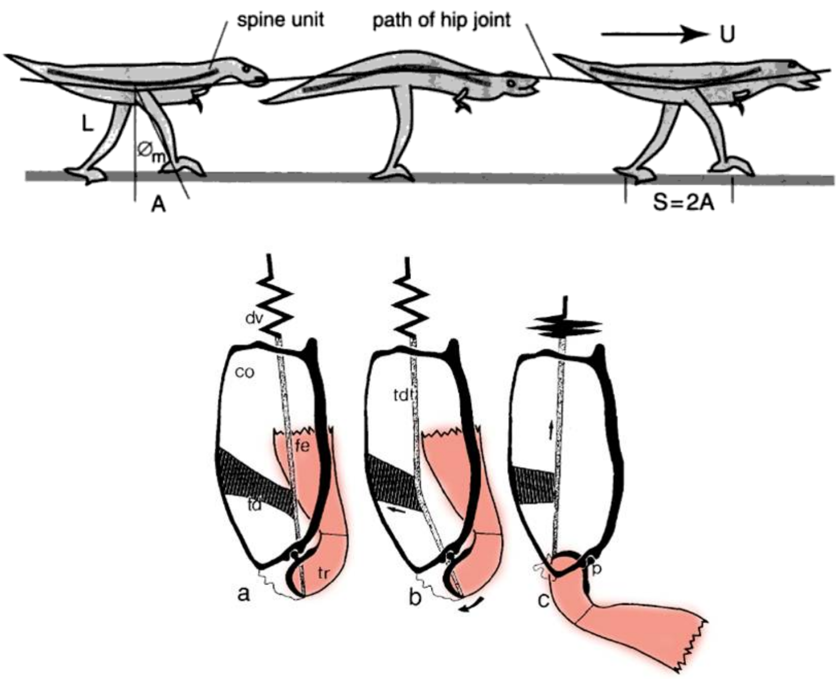

Figure 5. A 2 legged Bipedalus physiciensis elegans that make use of the oscillations in its spine for energy savings [25] and the flea jumping mechanism – the hind leg marked with green, at left the muscle is being tightened and at right the leg is starting the jump [26].

Problem area 4

The fourth problem area about navigation can be solved using magnetic fields or polarization patterns. The magnetic fields can be thought of as large guidelines that can be difficult to see unless the right sensors are available. Like a compass the sensors will indicate a direction. The magnetic field lines point more or less north-south and their vertical angle is different depending on the latitude. The horizontal angle is called the ‘declination’ and the vertical is the ‘inclination’. However a shortcoming is that the sensor does not tell which of the guiding lines that is followed – or formulated in another way: one will know how to head north but not the westward position.
The other solution was the use of polarization patterns in the sky. The patterns change slowly so the principle is here reminds of using the full moon as a guiding star.

Problem area 5

Problem area 5 was “Active shining in darkness“. Several of the creatures that emit light uses a light emitting substance called luceferin. When luceferin is oxidiced in the presence of a catalyst called luceferase it emits light. The process can be reversed by reducing (removing the oxygen) from the luceferin and in this way a rechargeable lamp should be possible.

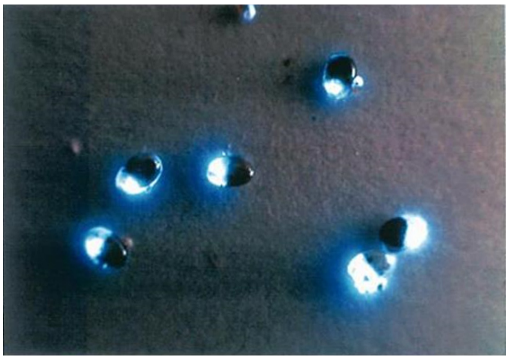

Figure 6. The glowing shellfish Cypridina Hilgendorfii [23, photo: Dr. Toshio Goto]

Problem area 6

Detection of victims in catastrophes, which was problem area 6, could be done using smell. There are 2 principles: One is to use a wide spectrum sensor (similar to the blood hound nose) to detect a variety of smells. Like the dog the sensor could be trained by smelling to a piece of clothes belonging to the missing person, or it could be trained to search for human type odours. The other principle is to use a simple sensor that only recognises a single olfactory agent that is characteristic to human beings – similar to the way a silk moth sense a single agent.

Problem area 7

One of the solutions to problem area 7 “Prevention of personal attack” is the “skunk” principle: to spray out a substance towards the aggressor that will make it/him go away. The substance could be something very stinky (like the skunk) but there are other possibilities. It could be a drug that will make the aggressor passive. The Bombardier Beetle shoots boiling water towards an aggressor. The heat and pressure is made in a chemical reaction.

3.5 Design

Having a number of different design principles the rest of the process is like normal designing. For each principle should alternative design concepts be formulated and drawn, see figure 7. This took place in the last week of the experiment.

For the first problem area a set of boots that ‘can walk on water’ was proposed. The concept is called ‘Aquagile’ (fig. 7A.) and is based on the 2 lifting power principles from the lizard. These are the impact reaction from slamming the water surface and a displacement of water that create temporary buoyancy. The person needs to run 6 steps a second to create enough lifting force and this is achieved with pneumatic soles that quickly can be inflated and deflated.

The second group was inspired by the kangaroo and combined the existing patented Poweriser jumping mechanism with a larger contact area and lower point of gravity to improve the cross country properties in rugged terrain. The contact area was increased using a three toe solution which is a simplified version of the kangaroo foot. The larger contact area makes the mechanism less sensitive to differences in level and surface hardness. The gravity point was lowered by placing the spring behind the leg. The solution called RoughJumber is shown in fig. 7B.

In problem area 3 focus is on resonance and eigenfrequency for energy conservation inspired by the wing driving mechanism in many insects. When part of the insect exoskeleton vibrates at its eigen-

Figure 7. Solution concepts for the 6 student groups: A. Aquagile, B. RoughJumber, C. Resonating skateboard, D. 3D compas, E. Lightpod, and F. ArmGuard.

frequency extra force to pull the wing downward is achieved. This principle was used to sketch a skateboard fitted with larger wheels and a pedal. The person on the skateboard steps repeatedly on the pedal that makes the wheels rotate. At a given speed a minimum of force is required to maintain the motion. The resonating skateboard is illustrated in figure 7C.

Problem area 4 focused on a low tech alternative to a GPS (Global Positioning System) based on magnetism. The system is inspired by migrating birds and marine animals and their magnetic field based orientation. The animals do not only sense where the magnetic pole is but also register the inclination of the magnetic field. The vertical angle of the magnetic field is dependent on the latitude and the animal therefore knows how far north or south it is. This is used to propose a 3D compass where a magnetic needle can rotate about two axes and be compared with both a vertical and a horizontal scale. Such a 3D compass will give 2 of the 3 needed coordinates – the longitude is missing. It is shown in figure 7D.

For problem area 5 a rechargeable lamp called LightPod was suggested based on the bioluminescence principles in the Cypridina Hilgendorfii shellfish. The shellfish makes two substances called luceferin and luciferase. When both are present together with oxygen light is emitted while luceferin is oxidized into oxyluceferin. The luceferin can be regenerated by reducing the oxyluceferin. The lightPod has four champers: Camper 1 holds pure water, chamber 2 has a reducing agent, chamber 3 holds the living shelfish, and chamber 4 is the mixing chamber. When the shellfish feels a raised pressure in the water coming from pulling one of the buttons on the lamp they emit the luceferin and luceferase into the water which is then directed into chamber 3 and the light is emitted. When all the luceferin is oxidized the reducing agent from chamber 2 regenerates the luceferin and the lamp will work again. The LightPod concept is shown in figure 7E.

The student in group 6 stopped on the course before reaching the design phase.

Group 7 made a self-defense mechanism called ArmGuard inspired by the Bombardier beetle and the skunk. The ArmGuard is a bracelet holding a spray with skunk-oil that can be fired toward an aggressor when the wearer feels unsafe. The oil should smell horrible but not be poisonous. Armguard is seen in figure 7F.

In general were all the proposed solutions only very rough design concepts which needs further detailing and experiments to find out if they work as imagined. However a physical mock-up of the resonance mechanism in the skateboard was made and showed that the principle works.

4. CONCLUSION

A biomimetic experiment has been made with the help of 12 experienced design engineering students that had no previous experience with biomimetics. For 7 selected problem areas a biomimetic search was done using commonly available university library books and online journals. The participants managed to do the searches with a minimum of instruction and came up with an impressive amount of biological analogies and useful design principles. Search results were focussed on a macro level looking mainly at animals and their behaviour. Biological analogies at the macro level have the advantage of being more straight forward to comprehend for mechanically oriented design engineers. The wealth of analogies at the micro level is much lager but require more biological knowledge to understand.

The results indicate that biomimetics has a promising potential as a design methodology helping the designer in the creative quest for ideas and inspiration. It also shows that engineering designers can benefit from the method and use it within a learning time of 2 weeks. Directly asked about their experiences the students mentioned the following points:

- Fun but also difficult to work with the nature and biological literature.
- Solutions that works in nature convinces and motivates further work.

ACKNOWLEDGEMENTS

Thanks goes to the participants in the experiment for good biomimetic work and an inspiring atmosphere: Kaspar Alvestad Stensletten, Mads Buur Mortensen, Hans Christian Stentoft-Christensen, Rasmus Nielsen, Jon Storm Madsen, Morten Lunde, Christoffer Viktor Smith, Jakob Halkjær Pedersen, Kasper Thorsager Jakobsen, Hans Christian Schubell, Magnus Edvard Nielsen and Rune Fogh. Thanks to Tomas Benzon for bringing a needed graphical improvement to figure 1.

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