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What is a Physicist Doing in the Jungle? Biomimetics of the Rainforest

Ille C. Gebeshuber[1,2,3,a] and Mark O. Macqueen[3,b]

[1]Institute of Microengineering and Nanoelectronics, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Malaysia

[2]Institute of Applied Physics, Vienna University of Technology, Wiedner Hauptstrasse 8-10/134, 1040 Wien, Austria

[3]Aramis Technologies, 14 Jalan BK 5D/1C, Bandar Kinrara, 47180 Puchong, Selangor, Malaysia

[a]gebeshuber@iap.tuwien.ac.at, [b]mark@aramis-tech.com

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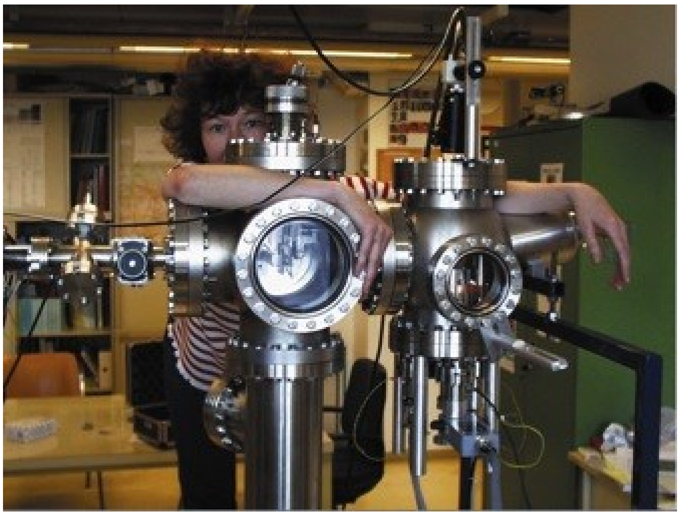
Abstract. This paper summarizes a TEDx Talk that the European physics professor Ille C. Gebeshuber, who has been living in South East Asia for nearly five years now, gave to a live audience of 800 in Kuala Lumpur, Malaysia, in July 2012. A similar talk is also given as an invited lecture at the 4th International Conference of Bionic Engineering in China in August 2013. The talk highlights the importance of news ways of doing science and of doing engineering that are needed to successfully address the major challenges humankind is currently facing, and how a generalistic approach synergistically combining Eastern and Western thinking might help in this respect. Biomimetics is stressed as an integrated, generalist way of learning from living nature, and as best practice example for developing new approaches that are based on understanding rather than learning by heart, with memory, reason and imagination as pillars, bridging fields of specialization and of education and thereby blending the knowledge of single isolated scientists and specialist scientist networks to a wisdom of the whole, powerful enough to help us successfully address our major problems.

Introduction

Having lived and worked in South East Asia for several years now, the European physics professor Ille C. Gebeshuber has broadened her horizon by getting to know and understand completely new ways of thinking, doing research, and dealing with problems. Her work is based on biomimetics and a deep understanding of trends and developments. On rainforest expeditions with her PhD students from Europe and Malaysia from fields such as economics, engineering, biology, the veterinary sciences, physics and the applied as well as the fine arts and collaborators from around the globe she has established an interdisciplinary sound basis to unveil the unique wisdom and potential of the largest sustainable system we know, living nature, and what we can learn from it regarding successful addressing of major global challenges such as climate change and sustainable development, major changes in biodiversity, supply with clean water for everybody and health problems due to resistant microorganisms [1,2]. The paper deals with the focus of her research: new ways of teaching, of disseminating and accessing knowledge, of doing engineering and shaping our approaches towards a better, healthy and good way of living, that would not compromise future generations.

The paper puts into text the TEDx Talk "What is a physicist doing in the jungle? Biomimetics of the rainforest" that the first author gave in Kuala Lumpur, Malaysia, in July 2012 to a live audience of 800. The talk is 22 minutes long and can be watched on the TED webpages http://tedxtalks.ted.com/video/What-is-a-physicist-doing-in-th; it reached more than 2000 views in the first two months it was online.

Doing Nanophysics at the Vienna University of Technology, Austria



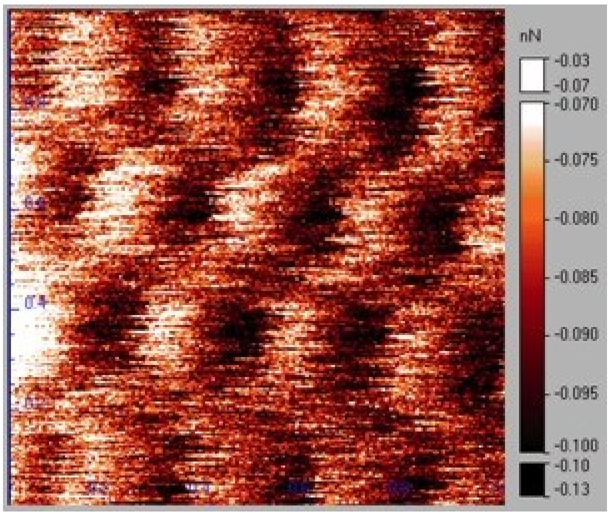


*Figure 1. Left: An ultrahigh vacuum atomic force microscope combined with a scanning tunnelling microscope (UHV AFM/STM). Right: Atomic force microscopy image of the surface of a highly oriented pyrolytic graphite (HOPG) crystal, image area 1*1 nm^2.*

The invention of the high resolution scanning probe microscopes at the end of the 1980s marked the beginning of the age of nanotechnology [3]. Such instruments allow for imaging of the surfaces of matter on the nanoscale (1 nm = 10^{-9} m) and also for manipulation of matter on such a small scale. Nanotechnology is a highly interdisciplinary field of research, and biology, chemistry, medicine, physics and materials science merge at such small scale to one convergent science.

Investigation of especially biological material on the nanoscale reveals amazing order, and hierarchical properties with added functionality on each length scale when stepwisely going up to the nanoscale. Bone with its various layers of hierarchy is an example for this [4,5].

Figure 1 (left) shows one of the sharpest microscopes in the world, an ambient temperature ultrahigh vacuum scanning tunneling atomic force microscope (UHV AFM/STM). Such instruments can image tiny areas, such as the one square nanometer image of the surface of an HOPG crystal (Fig. 1 right).

Work in nanoscience is exciting and rewarding, and the author enjoyed it for various years [6]. Then, she attended the European Technology Forum in Alpbach, Austria, and heard a presentation by somebody who was doing research of the global challenges for humankind. She discovered that there was something else than just investigating the beauty of the nanoscale. She felt that it was necessary to connect the different scientific results into a wider understanding of nature and developments. This can be done best by studying how nature integrates the different physical phenomena into working systems and organisms.

Albert Einstein once said “We can’t solve problems by using the same kind of thinking we used when we created them.” So, to broaden her approaches and ways of thinking, it was decided to move to a tropical multi-racial Islamic country – Malaysia, and look, listen and learn.

The Rainforest as a Research Laboratory

Since December 2008 the authors live and work in Malaysia and have the whole rainforest as their research laboratory. Rainforest expeditions with students open the mind, and teach to look at the solutions of nature. The flower from Figure 2 tricks pollinators such as flies by looking like fat meat. The interdisciplinarity that is hard to reach in most sciences is the most normal thing when PhD students and science collaborators from various fields go to the forest, and learn from its materials, structures and processes for novel approaches in the respective fields.

Figure 2. On scientific expedition in the Lata Jarum rainforest, Pahang, Malaysia. Rafflesia is a parasitic plant that lacks chlorophyll and bears a single, very large flower that sometimes smells of carrion, native to Malaysia and Indonesia [7].

Generalistic Aristotelian Approach

One might ask: Why the rainforest? To answer this we have to go back to one of the great man in science: Aristotle, the famous scientist and philosopher. He said "Nature does nothing uselessly". He did not assess the wonders of nature by mere measuring but by intensive observation and thinking about the reasons and mechanisms of its systems [8]. It is important not just to amass information but to "understand" the principles behind. Nature is the best designer we know and today, with our modern methods, with our high power microscopes, we can see that natural materials are tough, strong, self-repairing, etc.

Why is it so important to observe nature and its mechanisms? We must understand that our senses and measurement systems that are derived from them do not cover the whole area of reality. Our perception of nature is a kind of tunnel view that delivers only a small part of reality to us. So measuring a small part of nature does only give a very, very small amount of information to us. The systematic approach of "measuring" (i.e. Information generation) by specialists is extremely necessary but must be accompanied by an Aristotelian approach by generalists to understand the whole system as good as possible. For sure our models of explanation of the principles of nature can at best be a rough sketch of reality but an understanding of the whole system will allow us to see a bit more of the whole system than simple isolated measurements will provide. The better, generalist view of the whole system provides a wider viewing angle to the observer, an "Aristotelian Bonus" provides a better perspective and deeper insights into nature (Fig. 3).

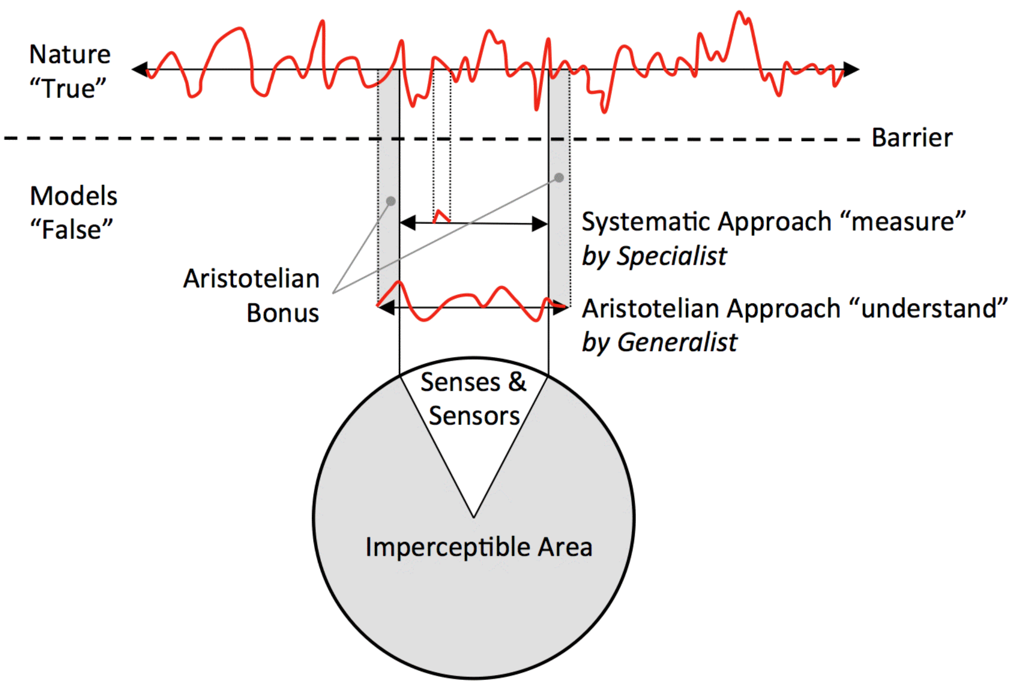


Figure 3. The proposed new way of thinking inspired by Aristotle's approach might provide understanding and an Aristotelian bonus that allow for successful addressing of the greatest challenges of our times.

The 15 Global Challenges as Identified by the Millennium Project

We need such an integrated approach because of various challenges we are currently facing. Every year, the United Nations publish the State of the Future report, where 15 global challenges (Fig. 4) are identified and ways how to potentially address them are given. The 15 global challenges are: 1. Sustainable development: How can sustainable development be achieved for all? 2. Water: How can everyone have sufficient clean water without conflict? 3. Population and resources: How can population growth and resources be brought into balance? 4. Democratization: How can genuine democracy emerge from authoritarian regimes? 5. Long-Term Perspectives: How can policymaking be made more sensitive to global long-term perspectives? 6. Information Technology: How can the global convergence of information and communications technologies work for everyone? 7. Rich–Poor Gap: How can ethical market economies be encouraged to help reduce the gap between rich and poor? 8. Health: How can the threat of new and reemerging diseases and immune microorganisms be reduced? 9. Capacity to Decide: How can the capacity to decide be improved as the nature of work and institutions change? 10. Peace and Conflict: How can shared values and new security strategies reduce ethnic conflicts, terrorism, and the use of weapons of mass destruction? 11. Status of Women: How can the changing status of women help improve the human condition? 12. Transnational crime: How can transnational organized crime networks be stopped from becoming more powerful and sophisticated global enterprises? 13. Energy: How can growing energy demands be met safely and efficiently? 14. Science and Technology: How can scientific and technological breakthroughs be accelerated to improve the human condition? 15. Global Ethics: How can ethical considerations become more routinely incorporated into global decisions?

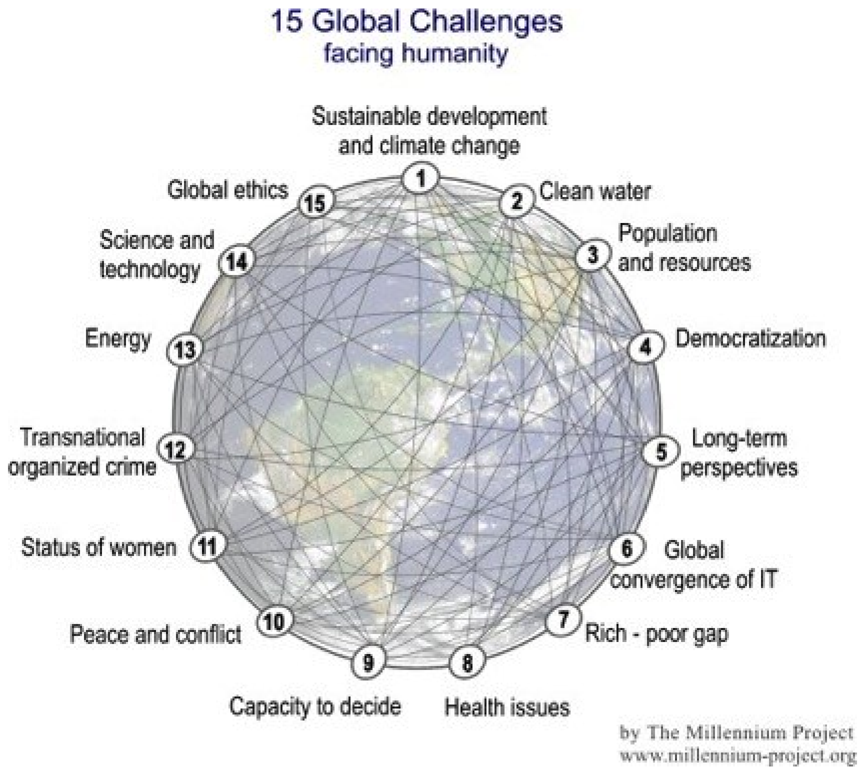


Figure 4. The 15 global challenges for humankind are annually identified by the Millennium project [9]. These challenges are interconnected and interdependent, and need to be addressed in a concerted action. © Millennium project, http://www.milennium-project.org

These challenges are not independent of each other. They are interconnected, interdependent, and we need to address them jointly, if we are to succeed. Living nature is a wonderful best practice directly at our doorstep, from whom we can learn such complex approaches. To do this, we need new ways of thinking, new ways of addressing our challenges. Western science has been very successful over many thousands of years, we know and have various wonderful insights, and our technology is highly elaborate: we can fly to the moon, we can control a robot on Mars. And yet, Western approaches also brought us to the stage where we are now. A stage where we face serious problems we need to address.

Western vs. Eastern Ways of Thinking

With a linear approach this might not be successful. The two images of airports in Munich, Germany, and in Jakarta, Indonesia (Fig. 5) should serve to illustrate the idea that we need a collaboration, a synergetic approach, combining linear Western thinking with more holistic Eastern approaches. The airport in Munich represents the linear Western approach. People sometimes have long straight walks to their respective terminals, and there are few common spaces to sit together, talk, discuss and relax. The airport in Jakarta looks completely different. The terminals are formed like grapes, in integrated structures. Short walkways bring the people to their planes, and there are lots of common spaces for shopping, eating, drinking and social activities.

Universitas Litterarum

We need new ways of science, new ways of thinking, new ways of doing things. Attempts to integrate knowledge, to make it accessible to a large amount of people were already undertaken in 1752, in the first encyclopedia by Diderot and D'Alembert. They established a tree of knowledge, and state that the major goal is understanding, and the basis for understanding are memory, reason and imagination. In most of today's science, the goal is not to understand, but to publish a paper.

And not just one, the more, the better. With minimum publishable amounts in each paper, and the way of writing too specialized that just further experts can read and appreciate the content. This is of no help for society, and definitely does not help to form an understanding of how to address global challenges. This needs to change. We again need to join forces, we need to again build a tree of knowledge, accessible for everybody, independent of level of education and field of specialization [13].

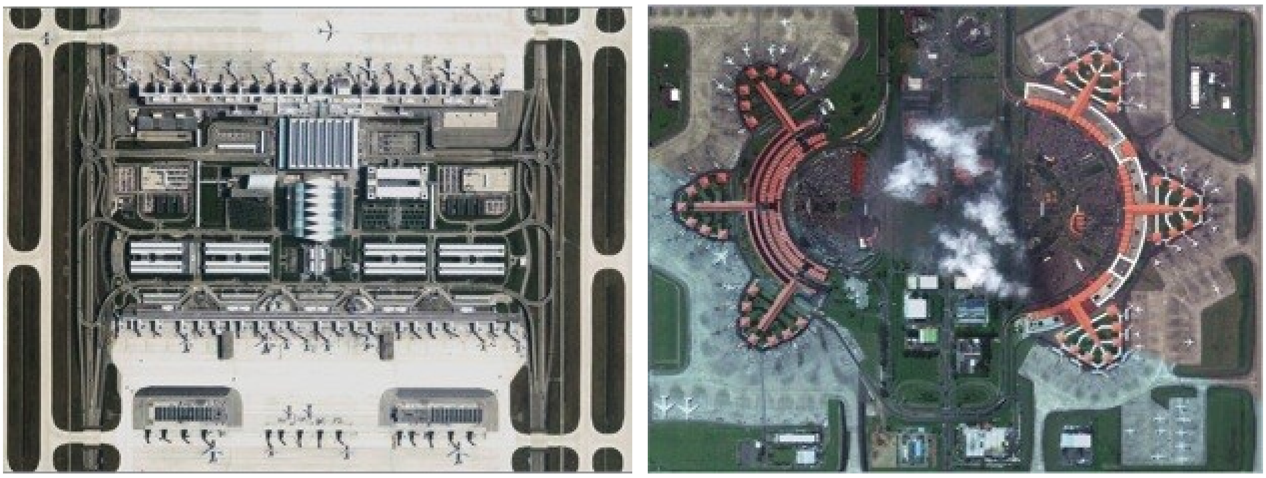


Figure 5. Left: Franz Josef Strauß airport in Munich, Germany, serving here as an illustration of the linear Western way of thinking and doing engineering. Right: The Soekarno-Hatta airport (Jakarta, Indonesia) serving as an illustration of the more integrated, holistic Eastern approach. © Google Earth

Examples from Living Nature: Raja Brooke's Birdwing

Raja Brooke's Birdwing (*Trogonoptera brookiana*) is the national butterfly of Malaysia (Fig. 7). It is an impressive example for structural colors, exquisite temperature regulation and knowledge-based rather than material based resource management.

If we look at living nature, one of the first things that strike us is the amazing combination of beauty, structure and function. This butterfly uses just local materials to achieve his coloration – no transport over thousands of miles. Not mining as we currently do, no resource depletion, but regrowing materials that achieve functionality via structure, and that even when the organism is dead serve as input for others (food, fertilizer). Structure rather than material is one deep principle that can be identified in living nature.

Examples from Living Nature: Selaginella Fern

The *Selaginella willdenowii* fern is another impressive example for structural colors from Malaysia's rainforests (Fig. 8). Depending on the viewing angle, it appears either blue or green. The coloration is an iridescent coloration that comes from two thin layers on the surface of the leaves, and the color is generated by interference [15]. When dried, the coloration disappears, and when rehydrated, the coloration reappears. In the leaves of this fern, beauty, structure and functionality meet.

Structural colors are one example how to use structure rather than material [16]. Transfer of this principle to engineering, to the textile industry and to medicine can result in less toxic and more benign ways to color items such as clothing and to detect diseases.

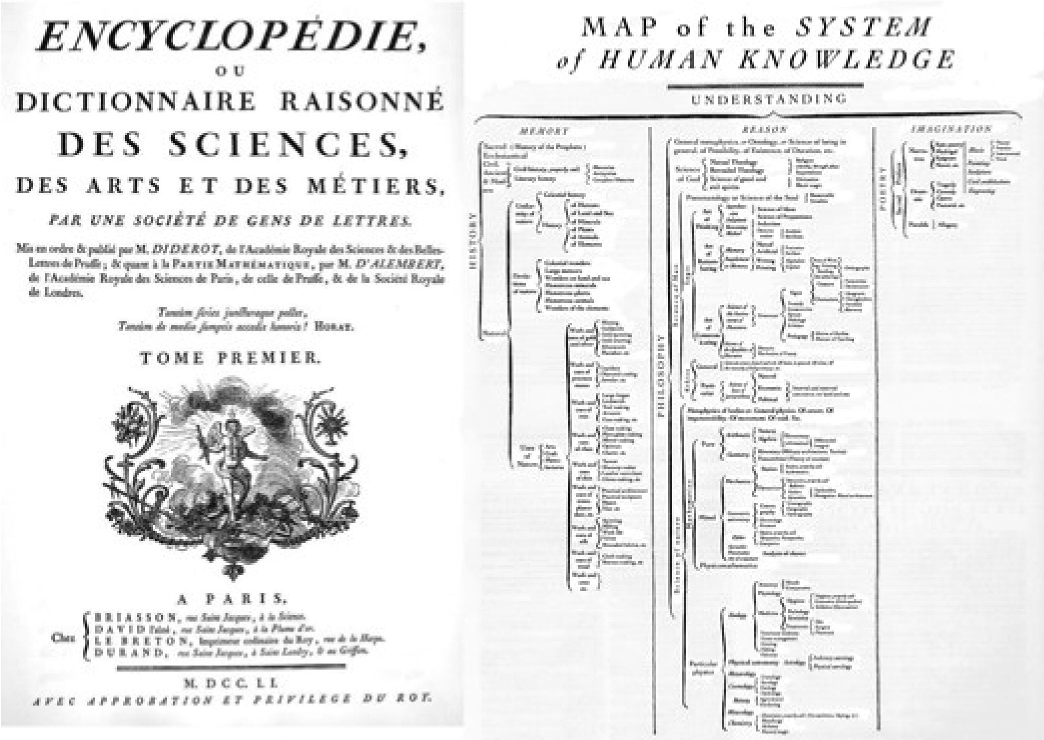


Figure 6. Left: Title page of the first encyclopedia, by Diderot and D'Alembert, 1752 [10-12]. Right: 'Tree of Knowledge' by Diderot and d'Alembert. The three pillars for understanding are reason, memory and imagination. English translation: © Benjamin Heller, University of Oxford, The Encyclopedia of Diderot and d'Alembert Collaborative Translation Project, http://quod.lib.umich.edu/d/did/tree.html.

*Figure 7. Raja Brooke's Birdwing (*Trogonoptera brookiana*) [14], the national butterfly of Malaysia. The green as well as the black coloration generates from minuscule structures and not from pigments, and serves various functions such as temperature regulation, camouflage and surface functionalization concerning self-cleaning. © seabagg, http://www.flickr.com/photos/seabagg/3923303391/*

Figure 8. The "peacock" fern Selaginella willdenowii*, a common plant in the Malaysian rainforest. © Mr. Foozi Saad, IPGM, Malaysia. Image reproduced with permission.*

Insects as Inspiration for Novel Navigation Systems

Living nature is amazing when seen from the point of view of an engineer. One example is the longhorn beetle depicted in Figure 10. We usually oversee the beauty of nature as we are used to our environment. But a close-up of for example an insect shows how magnificent their design is. Watch the form of the external armor, the facet eyes, the movable antennae (ball joints, interesting for tribologists), the mandibles, it can walk, fly and replicate itself. Here materials, structures and functions are all integrated into a tiny object! The science of biomimetics identifies deep principles in living nature and transfers them to science, engineering and the arts. In a nutshell we can say that biomimetics is the abstraction of good design from nature. From a similar insect, the first author and her team of Malay PhD students developed a navigational system that works without using satellites, just using the polarization of the skylight, similar to the navigation of bees and desert ants [17].

The materials of the longhorn beetle (and actually of every organism) are locally harvested, and assembled at benign conditions. No mining, transport of goods, and external assembly is necessary – in this way, the resource management of organisms is fundamentally different from current human engineering. And furthermore, most processes in Nature are cyclic, with no or very little waste – the waste of one organism (or the whole organism, when it dies) becomes food or fertilizer for other organisms. Human engineering can learn from such natural approaches, and start to develop a new type of engineering, inspired by the natural one, which is rather knowledge intense (cf. genetic programming) rather than resource intense.

Figure 10. Macro photograph of a longhorn beetle from Pontianak, Kalimantan, Indonesian Borneo, Indonesia. © Iwan Ramawan. Image reproduced with permission.

Slime Mold Life Cycle inspiring Collaboration of Scientists

Iridescence is a beautiful property of some living creatures (and also occurs in CDs, DVDs, oil films on water, rainbows and soap bubbles) [18]. A strikingly iridescent organism is the slime mold depicted in Figure 11 left. The complex life cycle of the slime mold can be used to illustrate the current need that scientists join forces to successfully address the global challenges for humankind.

Slime molds live as independent single cells, until conditions turn bad (e.g., no food). In this case, they group up and build an organism. The single cells loose their ability to survive on their own. All work together for survival [19]. They build a stalk, on top of the stalk is a ball (the mature sporangium), this then "explodes" and sends new life out. Far out - where there will hopefully be better conditions for survival.

Conclusions, Outlook – and an Invitation

Diversity is important as input to the engineering sciences. The magic ingredients in studying nature to gain understanding of trends and developments and to become able to introduce new ways of doing things are not like following a cooking recipe or choosing a robot like approach, but "curiosity" and openness to the wonders of nature. We need to thrive to understand the interconnectedness and interdependencies in living nature and to transfer their basic principles to our approaches in science technology and engineering for a better future for humanity and successful addressing the global challenges.

Our current times, with the Internet and knowledge at our fingertips, contribute greatly to breeding the new type of scientist who is needed to introduce such new approaches. The role of the teachers are changing, the roles of the students are changing, and convergent sciences such as nanotechnology are paving the way towards a more integrated approach to science.

Figure 12 depicts the first author of the paper, and rangers and a further researcher from UKM (Dr. Faszly Rahim, an insect specialist) and is an invitation to interested readers to join the team on a rainforest expedition and learn first hand from this great, sustainable system, living nature, that we have at our doorsteps.

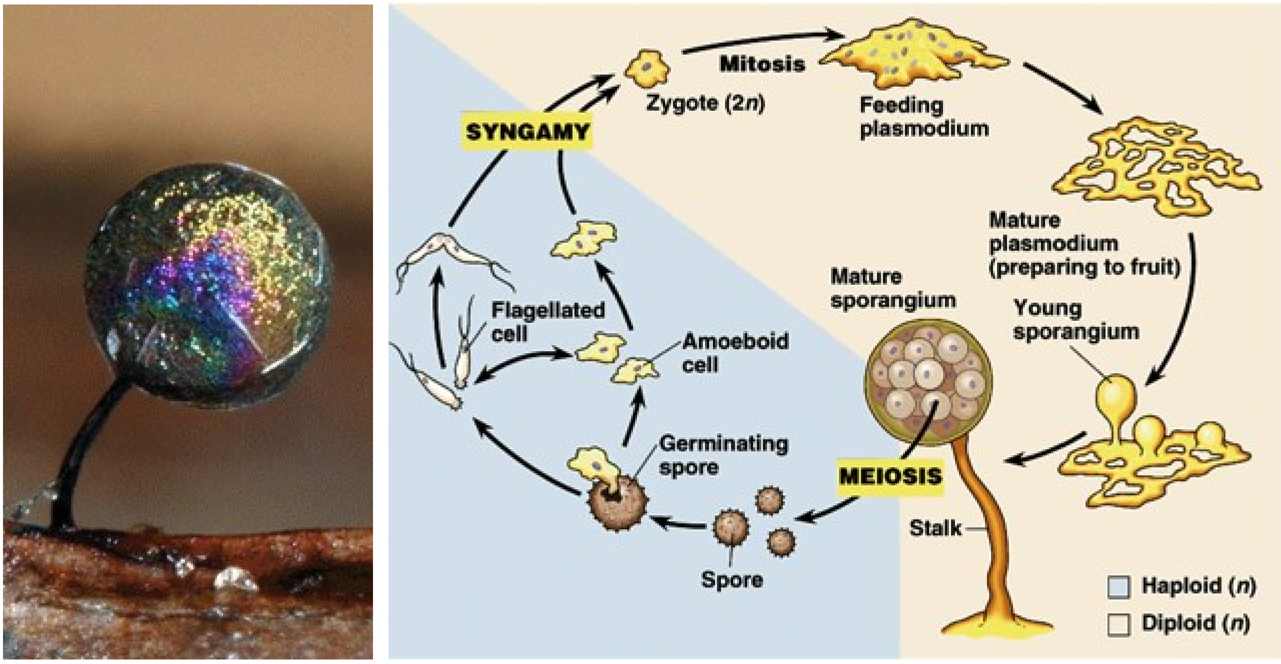


Figure 11. Left: The mature sporangium of an iridescent slime mold. © T.I. Krivomaz (2010) Myxomycetes of Ukraine (webpage, not online anymore). Right: Life cycle of a slime mold. © Pearson Education Inc., publishing as Benjamin Cummings.

Figure 12. UKM researchers and rangers in the Lata Jarum Rainforest, Pahang, Malaysia.

Acknowledgments

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