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Lifelong Learning Programme

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A CASE STUDY ON
NANOTECHNOLOGY AND NANOBIOMIMICRY

by

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INTRODUCTION/BACKGROUND

Nanotechnology represents the study of the control of matter on an atomic and molecular scale. Generally nanotechnology deals with structures of the size 100 nanometers or smaller, and involves developing materials or devices within that size. Nanotechnology is very diverse, ranging from novel extensions of conventional device physics, to completely new approaches based upon molecular self-assembly, to developing new materials with dimensions on the nano-scale, even to speculation on whether we can directly control matter on the atomic scale.

As a specific area, ***biomimicry*** or ***biomimetics*** represents the examination of the nature, its models, systems, processes, and elements to emulate or take inspiration from in order to solve human problems. The term *biomimicry* and *biomimetics* come from the Greek words bios, meaning life, and mimesis, meaning to imitate. Similar terms include ***bionics***.
Over the last 3.6 billion years, nature has gone through a process of trial and error to refine the living organisms, processes, and materials on planet Earth. The emerging field of biomimetics has given rise to new technologies created from biologically inspired engineering at both the macro scale and nanoscale levels. Biomimetics is not a new idea. Humans have been looking at nature for answers to both complex and simple problems throughout our existence. Nature has solved many of today's engineering problems such as hydrophobicity, wind resistance, self-assembly, and harnessing solar energy through the evolutionary mechanics of selective advantages.
The term *biomimicry* appeared as early as 1982. Biomimicry was popularized by scientist and author *Janine Benyus* in her 1997 book *Biomimicry: Innovation Inspired by Nature*. Biomimicry is defined in the book as a "new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems". Benyus suggests looking to Nature as a "Model, Measure, and Mentor" and emphasizes sustainability as an objective of biomimicry.

DEFINITIONS

a. ***Biomimetics***, also known as ***bionics***, ***biognosis***, or ***biomimicry***, is the use and implementation of concepts and principles from nature to creating new materials, devices and systems. This adaptation of methods and systems found in nature into synthetic constructs is desirable because evolutionary pressure typically forces natural systems to become highly optimized and efficient. Nature provides a database of several solutions that already work and thus serve as models of inspiration for synthetic paradigms.

Biomimetics, in fact, has its origins back in the times when the Wright brothers modeled their planes on the structure of bird wings; when Joseph Paxton used the design of a lily pad to structure the Crystal Palace and when Leonardo da Vinci was working on his flying machines and ships. However the field was only given its official name and definition by Jack Steele of the U.S. Force in the 1960's.

Biomimicry only recently begun to reach its full potential since the invention of Velcro, the biomimetic-equivalent of hooks in natural burrs created by George de Mestral in 1948. Since then, many facets have evolved and can be broadly categorized under two main topics:

- Mimicking mechanisms found in nature - e.g. water-proof glue developed with parallel mechanisms found in the study of adhesives produced by mollusks.
- Utilizing or incorporating nature itself into novel devices - e.g. new strong but light materials have come from studying the structure of bone.

b. ***Biomimetics*** is the ability to manipulate atoms at the atomic level ranging from one to several nanometers in order to understand, create and use material structures, devices and systems with fundamentally new properties and functions resulting from their small structure.

All biological systems have their most basic properties and functions defined at the nanoscale from their first level of organization. The overall aim of nanotechnology in biological systems then is to hierarchically assemble molecules into objects and vice versa, using bonds that require low energy consumption. Nanotechnology provides tools and platforms for the investigation and transformation of biological systems, and biology serves as the source of inspiration for creating new devices and systems integrated from the nanoscale under the two facets already outlined above.

It is important to note that biological models cannot be emulated exactly as they operate on a much smaller time-scale than usually necessary in industry and also require water while industrial processes work in various other media.

c. ***Confluence of Nanotechnology and Biomimetics*** - most of the applications developed in the past have been created on the macromolecular level. Only recently has Biomimetics begun to approach the micro and sub-micro molecular level of matter. At the turn of the century, however, the interests

of scientists and researchers have shifted towards thinking of matter at the atomic level hence the field Nanotechnology: **Nanobiomimicry.**
The "bio" comes from the Greek root meaning life; "mimicry," or to mimic, means to copy. Add "nano" to the front, which narrows the structures in question down to the nanoscopic scale (say from 1 to 100 nanometers) and you have "nanobiomimicry."
Biological imitation of nano and macro scale structures and processes is called nanobiomimicry. Nature provides a great variety of nano-sized materials that offer as potential templates for the creation of new materials, such as bacteria, viruses, diatoms, and biomolecules. Through the study of nanobiomimicry, key components of nanodevices like nanowires, quantum dots, and nanotubes have been produced in an efficient and simple manner when compared to more conventional lithographic techniques. Many of these biologically derived structures are then developed into applications for photovoltaics, sensors, filtration, insulation, and medical uses. The field of nanobiomimetics is highly multidisciplinary, and requires collaboration between biologists, engineers, physicists, material scientists, nanotechnologists and other related fields. In the past century, the growing field of nanotechnology has produced several novel materials and enabled scientists to produce nanoscale biological replicas.
Living organisms and natural phenomena have certain behaviours and properties which let them exist in harmony with the surrounding environment. By understanding these natural processes, we develop new technology to venture into new territory.

PURPOSE

The purpose of the activity is to discover few things that nanotechnologists have learned from *Mother Nature*. Here’s the proposed list:

1. Lotus effect
The *lotus effect* refers to the very high water repellence (superhydrophobicity) exhibited by the leaves of the lotus flower (Nelumbo). Dirt particles are picked up by water droplets due to a complex micro- and nanoscopic architecture of the surface, which minimizes adhesion.
This effect can easily be demonstrated in many other plants, for example Tropaeolum (nasturtium), Opuntia (prickly pear), Alchemilla, cane, and on the wings of certain insects.
The phenomenon was first studied by Dettre and Johnson in 1964 using rough hydrophobic surfaces. Their work developed a theoretical model based on experiments with glass beads coated with paraffin or PTFE telomer. The self-cleaning property of superhydrophobic micro-nanostructured surfaces was studied by Barthlott and Ehler in 1977, and perfluoroalkyl and perfluoropolyether superhydrophobic materials were developed by Brown in 1986 for handling chemical and biological fluids. Other biotechnical applications have emerged since the 1990s.

Some nanotechnologists have developed treatments, coatings, paints, roof tiles, fabrics and other surfaces that can stay dry and clean themselves in the same way as the lotus leaf. This can usually be achieved using special fluorochemical or silicone treatments on structured surfaces or with compositions containing micro-scale particulates. Super-hydrophobic coatings comprising Teflon microparticles have been used on medical diagnostic slides for over 30 years. It is possible to achieve such effects by using combinations of polyethylene glycol with glucose and sucrose (or any insoluble particulate) in conjunction with a hydrophobic substance.

As self-cleaning of superhydrophobic microscopic to nanoscopic surfaces is based on a purely physio-chemical effect it can be transferred onto technical surfaces on a biomimetic basis. One example of the products with superhydrophobic self-cleaning properties is the facade paint Lotusan.

Further applications have been marketed, such as self-cleaning glasses installed in the sensors of traffic control units on German autobahns developed by a cooperation partner (Ferro GmbH). Evonik AG has developed a spray for generating self-cleaning films on various substrata. Lotus effectsuperhydrophobic coatings applied to microwave antennas can significantly reduce rain fade and the buildup of ice and snow. "Easy to clean" products in ads are often mistaken in the name of the self-cleaning process of the lotus-effect. Patterned superhydrophobic surfaces also show promise for "lab-on-a-chip" microfluidic devices and can greatly improve surface-based bioanalysis.

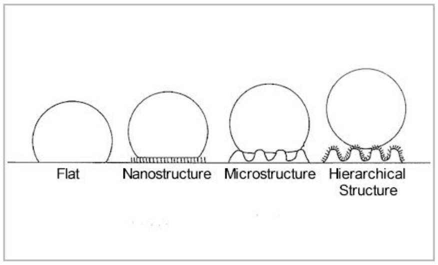
The lotus flower is sort of like the sharkskin of dry land. The flower's micro-rough surface naturally repels dust and dirt particles, keeping its petals sparkling clean. If you've ever looked at a lotus leaf under a microscope, you've seen a sea of tiny nail-like. A German company, spent four years researching this phenomenon and has developed a paint with similar properties. The micro-rough surface of the paint pushes away dust and dirt, diminishing the need to wash the outside of a house.

You don't have to wash your house if you can make it more like a Lotus leaf. The Lotus leaf is even more intriguing - and more hydrophobic. Some leaves have a measured water contact angle as high as 170°. In my experience, it's difficult to achieve a water contact angle in excess of about 120° with a flat surface. However, if you add either nanostructures (like nanotubes) or a microstructure, the contact angle can be increased. In the case of the Lotus leaf, however, it has both microstructures and nanostructures.

This double or hierarchical structure (as illustrated in the graphic below) further increases the contact angle and lowers the contact angle hysteresis. Dr. Wilhelm Barthlott, a botanist at the University of Bonn (Germany), discovered the secret behind the Lotus leaf thirty years ago and patented the discovery calling it the Lotus Effect.

As a result of the non-wetting surface, the Lotus leaf is the archetype for self-cleaning surfaces.

Nanotechnologists have developed a number of commercial products that mimic the hierarchical structure of the Lotus plant. Among them is StoCoat Lotusan2 paint -- which is what you need to paint your house with to make itself cleaning. The video below illustrates the self-cleaning properties of a surface coated with Lotusan.



2. Biomorphic mineralization is a technique that produces materials with morphologies and structures resembling those of natural living organisms by using bio-structures as templates for mineralization. Compared to other methods of material production, biomorphic mineralization is facile, environmentally benign and economic. Biomorphic mineralization makes efficient use of natural and abundant materials such as calcium, iron, carbon, phosphorus, and silicon with the capability of turning biomass wastes into useful materials. Templates derived from biological nanoparticles such as DNA, viruses, bacteria, and peptides can transform unordered inorganic nanoparticles into complex inorganic nanostructures. Biologically derived nanostructures are typically fabricated using either chemical or physical techniques. Typical chemical fabrication techniques are plasma spraying, plasma immersion ion implantation and deposition, sol-gel, chemical vapor deposition, physical vapor deposition, cold spraying and self-assembly. Physical modification techniques include laser etching, shot blasting, physical plating, and physical evaporation and deposition. Methods of fabrication with high throughput, minimal environmental damage, and low costs are highly sought after.

3. Biologically inspired engineering

The use of biomineralized structures is vast and derived from the abundance of nature. From studying the nano-scale morphology of living organisms many applications have been developed through multidisciplinary collaboration between biologists, chemists, bioengineers, nanotechnologists, and material scientists.

4. Nanowires, nanotubes, and quantum dots

A virus is a nonliving particle ranging from the size of 20 to 300 nm capsules containing genetic material used to infect its host. The outer layer of viruses are remarkably robust and capable of withstanding temperatures as high as 60 °C and stay stable in a wide range of pH range of 2-10. Viral capsids can be used to create several nano device components such as nanowires, nanotubes, and quantum dots. Tubular virus particles such as thetobacco mosaic virus (TMV) can be used as templates to create nanofibers and nanotubes since both the inner and outer layers of the virus are charged surfaces and can induce nucleation of crystal growth. This was demonstrated though the production of platinum and gold nanotubes using TMV as a template. Mineralized virus particles have been shown to withstand various pH values by mineralizing the viruses with different materials such silicon, PbS, and CdS and could therefore serve as a useful carriers of material. A spherical plant virus called cowpea chlorotic mottle virus (CCMV) has interesting expanding properties when exposed to environments of pH higher than 6.5. Above this pH, 60 independent pores with diameters about 2 nm begin to exchange substance with the environment. The structural transition of the viral capsid can be utilized in Biomorphic mineralization for selective uptake and deposition of minerals by controlling the solution pH. Applications include using the viral cage to produce uniformly shaped and sized quantum dot semiconductor nanoparticles through a series of pH washes. This is an alternative to theapoferritin cage technique currently used to synthesize uniform CdSe nanoparticles. Such materials could also be used for targeted drug delivery since particles release contents upon exposure to specific pH levels.

5. Display technology

Vibrant blue color of Morpho butterfly due to structural coloration. Morpho butterfly wings contain microstructures that create its coloring effect through structural coloration rather than pigmentation. Incident light waves are reflected at specific wavelengths to create vibrant colors due to multilayer interference, diffraction, thin film interference, and scattering properties. The scales of these butterflies consist of microstructures such as ridges, cross-ribs, ridge-lamellae, and microribs that have been shown to be responsible for coloration. The structural color has been simply explained as the interference due to alternating layers of cuticle and air using a model of multilayer interference. The same principles behind the coloration of soap bubbles apply to butterfly wings. The color of butterfly wings is due to multiple instances of constructive interference from structures such as this. The photonic microstructure of butterfly wings can be replicated through biomorphic mineralization to yield similar properties. The photonic microstructures can be replicated using metal oxides or metal alkoxides such as titanium sulfate (TiSO4), zirconium oxide (ZrO2), and aluminium oxide (Al2O3).

An alternative method of vapor-phase oxidation of SiH4 on the template surface was found to preserve delicate structural features of the microstructure. Now, companies like Qualcomm are specializing in creating color displays with low power consumption based on these principles.

6. Structural coloration

The brilliant iridescent colours of the male Peacock's tail feathers are created by structural coloration, as first noted by Isaac Newton and Robert Hooke.

Structural coloration is the production of colour by microscopically structured surfaces, sometimes also called schemo-chromes, fine enough to interfere with visible light, sometimes in combination with pigments: for example, peacock tail feathers are pigmented brown, but their structure makes them appear blue, turquoise, and green, and often they appear iridescent.

Structural coloration was first observed by English scientists Robert Hooke and Isaac Newton, and its principle – wave interference – explained by Thomas Young a century later. Young correctly described iridescence as the result of interference between reflections from two (or more) surfaces of thin films, combined with refraction as light enters and leaves such films. The geometry then determines that at certain angles, the light reflected from both surfaces adds (interferes constructively), while at other angles, the light subtracts. Different colours therefore appear at different angles.

In animals such as on the feathers of birds and the scales of butterflies, interference is created by a range of photonic mechanisms, including diffraction gratings, selective mirrors, photonic crystals, crystal fibres, matrices of nanochannels and proteins that can vary their configuration. Many of these mechanisms correspond to elaborate structures visible by electron microscopy. In plants, brilliant colours are produced by structures within cells. The most brilliant blue coloration known in any living tissue is found in the marble berries of Polliacondensata, where a spiral structure of cellulose fibrils produces Bragg's law scattering of light.

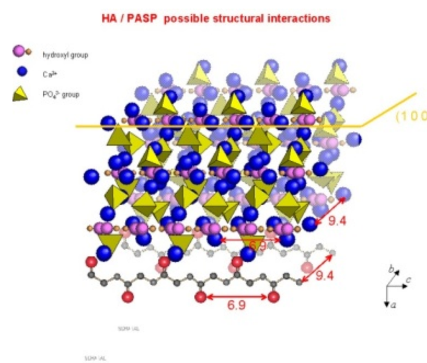
Structural coloration has potential for industrial, commercial and military application, with biomimetic surfaces that could provide brilliant colours, adaptive camouflage, efficient optical switches and low-reflectance glass.

7. Flock of sheep

Holistic planned grazing, using fencing and/or herders, seeks to restore grasslands by carefully planning movements of large herds of livestock to mimic the vast herds found in nature where grazing animals are kept concentrated by pack predators and must move on after eating, trampling, and manuring an area, returning only after it has fully recovered. Developed by Allan Savory, this method of biomimetic grazing holds tremendous potential in building soil, increasing biodiversity, reversing desertification, and mitigating global warming, similar to what occurred during the past 40 million years as the expansion of grass-grazer ecosystems built deep grassland soils, sequestering carbon and cooling the planet.

8. Biomimetic crystallization and structural analysis

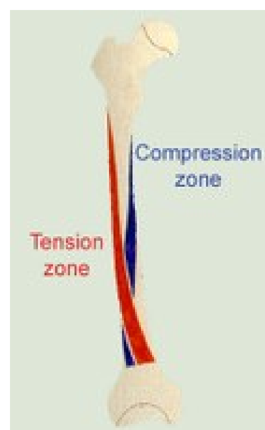
A relevant biomimetic strategy involves the use of organic molecules or macromolecules to modulate the crystal structure, crystallinity, morphology and stability through specific or non-specific interactions that mimic those occurring among acidic macromolecules and biogenic crystals.



The study of the effect of polyelectrolytes, polymers, drugs and isomorphous substitutions on the structure, morphology, chemistry and relative stability of calcium phosphates of biological interest provides a tool to investigate the role of matrix constituents in mineralization and the interaction of drugs with the biogenic mineral.

9. Biomineralized tissues

Femur bone

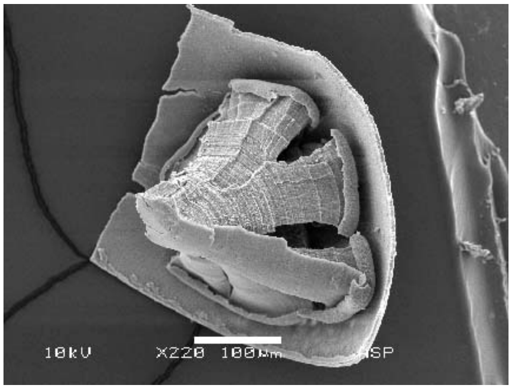


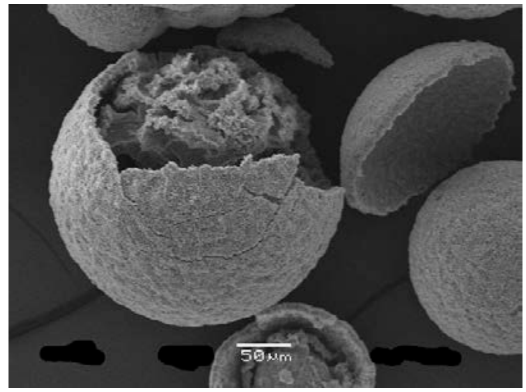
Biomimetics approaches the design and synthesis of new functional materials using the strategies adopted by living organisms to produce the biological ones. Biomineralized tissues often display unique and desirable morphological, structural and mechanical properties, and represent informative models for the development of complex functional materials.

The research involves the structural, morphological and chemical study of the mineral phase and of the macromelecular component of hard tissues, as well as a thorough investigation of the structure - function relationships in biomineralized tissues.

10. Inorganic-polymeric complex architectures

The production of composite materials made up of calcium phosphates and polymers is of great interest for the development of biomaterials suitable to repair the skeletal system. The research is aimed to the design and development of inorganic-polymeric composites with complex architectures, including hollow microspheres, core/shell and porous micro-fibrous structures, with potential applications as bioactive molecules delivery systems and porous scaffolds.



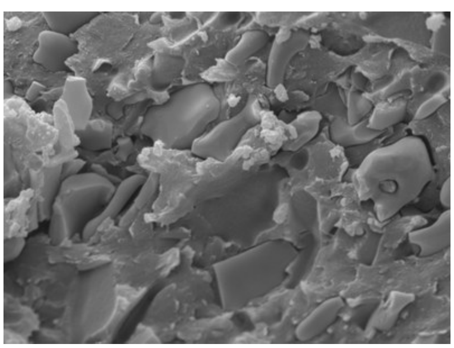


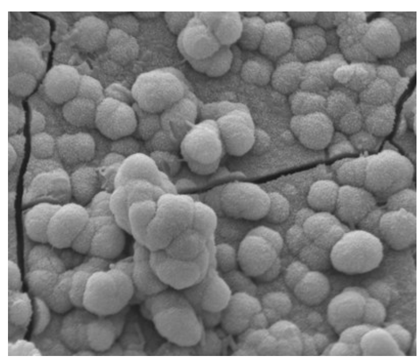
11. Template directed synthesis

HA thin film

Biomineralization processes usually involve both structural and acidic macromolecules. Acidic macromolecules are rich in negatively charged groups, which promote their interaction with the charged inorganic crystal surfaces. The interaction can be specific, with the protein adopting a conformation and exhibiting charge distribution and repeating distances matching some structural motif of the crystal, or even non-specific, due to multiple electrostatic interactions. These macromolecules are believed to control nucleation, polymorphism, growth, chemical composition, shape, dimensions, orientation and texture of the inorganic crystals.

The research activity is aimed to study the nucleation and growth of calcium phosphates on functionalized matrices, in order to develop innovative biomimetic processing strategies for producing ceramic thin films with a wide range of potential applications. Moreover, these studies provide interesting information useful for a deeper understanding of the phenomen.





12. Porous scaffolds for regenerative medicine

Regenerative medicine exploits strategies aimed at developing new complex materials with hierarchical 3D architectures, able to interact with living cells, and to promote tissue repair. The aim is to get a tissue identical with the original one, in the case of bone tissue it is based on threedimensional (3D) scaffold, possibly enriched with signal molecules, such as growth factors, and cells. The research activity is focused to develop porous scaffolds, with interconnected pore network structure and tailored physical and biochemical properties for cellular in-growth, revascularization, adequate nutrition and oxygen supply. To this aim we employ biomimetic materials based on calcium phosphates and biodegradable polymers through cement-like setting reactions and freeze-drying methods.

13. Burr = Velcro

Velcro was inspired by the tiny hooks found on the surface of burs. Researchers studied the termite's ability to maintain virtually constant temperature and humidity in their termite mounds in Africa despite outside temperatures that vary from 1.5 °C to 40 °C (35 °F to 104 °F). Researchers initially scanned a termite mound and created 3-D images of the mound structure, which revealed construction that can influence human building design. The Eastgate Centre, a mid-rise office complex in Harare, Zimbabwe, stays cool without air conditioning and uses only 10% of the energy of a conventional building its size.

Modeling echolocation in bats in darkness has led to a cane for the visually impaired. Research at the University of Leeds, in the United Kingdom, led to the UltraCane, a product formerly manufactured, marketed and sold by Sound Foresight Ltd.

Janine Benyus refers in her books to spiders that create web silk as strong as the Kevlar used in bulletproof vests. Engineers could use such a material—if it had a long enough rate of decay—for parachute lines, suspension bridge cables, artificial ligaments for medicine, and other purposes.

Other research has proposed adhesive glue from mussels, solar cells made like leaves, fabric that emulates shark skin, harvesting water from fog like abeetle, and more. Nature’s 100 Best is a compilation of the top hundred different innovations of animals, plants, and other organisms that have been researched and studied by the Biomimicry Institute.

A display technology based on the reflective properties of certain morpho butterflies was commercialized by Qualcomm in 2007. The technology usesInterferometric Modulation to reflect light so only the desired color is visible in each individual pixel of the display

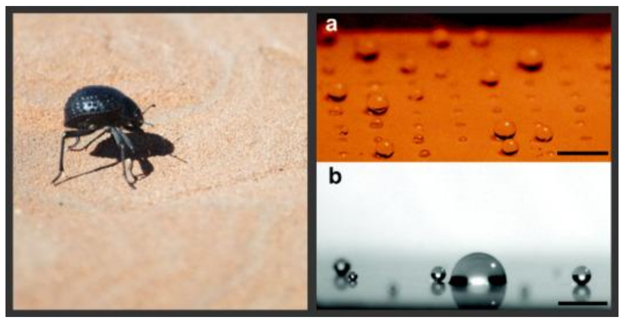
Biomimicry may also provide design methodologies and techniques to optimize engineering products and systems. An example is the re-derivation of Murray's law, which in conventional form determined the optimum diameter of blood vessels, to provide simple equations for the pipe or tube diameter which gives a minimum mass engineering system.

In structural engineering, the Swiss Federal Institute of Technology (EPFL) has incorporated biomimetic characteristics in an adaptive deployable "tensegrity" bridge. The bridge can carry out self-diagnosis and self-repair.

The Bombardier beetle's powerful repellent spray inspired a Swedish company to develop a "micro mist" spray technology, which is claimed to have a low carbon impact (compared to aerosol sprays). The beetle mixes chemicals and releases its spray via a steerable nozzle at the end of its abdomen, stinging and confusing the victim.

14. Bug = Water collection

The Stenocara beetle is a master water collector. The small black bug lives in a harsh, dry desert environment and is able to survive thanks to the unique design of its shell. The Stenocara's back is covered in small, smooth bumps that serve as collection points for condensed water or fog. The entire shell is covered in a slick, Teflon-like wax and is channeled so that condensed water from morning fog is funneled into the beetle's mouth. It's brilliant in its simplicity.



Researchers at MIT have been able to build on a concept inspired by the Stenocara's shell and first described by Oxford University's Andrew Parker. They have crafted a material that collects water from the air more efficiently than existing designs. About 22 countries around the world use nets to collect water from the air, so such a boost in efficiency could have a big impact.

15. Sharkskin = Swimsuit

Sharkskin-inspired swimsuits received a lot of media attention during the 2008 Summer Olympics when the spotlight was shining on Michael Phelps.

Seen under an electron microscope, sharkskin is made up of countless overlapping scales called dermal denticles (or "little skin teeth"). The denticles have grooves running down their length in alignment with water flow. These grooves disrupt the formation of eddies, or turbulent swirls of slower water, making the water pass by faster. The rough shape also discourages parasitic growth such as algae and barnacles.

Scientists have been able to replicate dermal denticles in swimsuits (which are now banned in major competition) and the bottom of boats. When cargo ships can squeeze out even a single percent in efficiency, they burn less bunker oil and don't require cleaning chemicals for their hulls. Scientists are applying the technique to create surfaces in hospitals that resist bacteria growth - the bacteria can't catch hold on the rough surface.

OBJECTIVES

The lesson (project) designed for the *IXth form students*, sought to develop the knowledge, skills and attitudes of pupils involved, so that they can participate effectively in discussions on topical issues. At the same time, it stressed the direct exchanges of ideas and experience, for students involved in the project, to take a clearer picture of the investigative approach in action.
The proposed activities trying to address the achievement of the objectives, which although are not specific, but lead to the idea that Science contribute to the formation of young people as unique individuals, able to discern and to take informed decisions. In this respect, the objectives are the following:
- increasing the interest of students towards civic issues as well as to the scientific findings;
- training the young people to express their views on various Science issues;
- acquiring (by students) of investigative capacities and skills;
- stimulating students' desire to deepen the understanding of the current problems of the actual society;
- increasing the students' confidence and their self-esteem to be involved in the discussion of scientific issues that can be found in ordinary and specialized newspapers.

From the scientific point of view, the lesson activities allow students to learn about the defined characteristics of:
- certain physical systems encountered in the wild;
- nanotechnologies phenomena;
- possibilities of practical application related to theoretical knowledge of nanotechnologies;
- phenomena in the field of nanotechnologies;
- physical characteristics of the phenomena in the field of nanotechnologies;
- causal existed relations;
- carrying out the physical phenomena specific to nanotechnologies;
- application of the knowledge gained through the study of Science in related fields;
- presentation (in written or oral form) of the results of an investigative approach using specific Science terminology;
- advantages and disadvantages of nanotechnologies from the environmental perspective.

LEARNING RESULTS

When acquiring the information and after realizing the activities, students are able to:

- edit a report where to submit arguments in respect of decisions taken and the related reasons;
- identify the consequences of applying nanotechnologies to human health, environment and society;
- retrieve specific information in the proposed websites;
- analyze selected information in relation to the proposed questions;
- decide as a group what the effects of applied nanotechnologies are;
- analyze the pros and cons of applied nanotechnologies;
- work in groups to conclude what are the advantages of the models imitation of nature;
- submit collective conclusions made in front of the students, in the class.

CLASSROOM MANAGEMENT & SEQUENCE OF EVENTS

The lesson ***Nanobiomimicry*** proposes a different approach to this topic. The adopted strategy is represented by the format of exchanging of ideas and arguments, in order to take a proper decision.

1. Introduction and formation of groups

The theme is presented and recalls the review / presentation of the necessary definitions. The class is divided into groups of students. In order to assess the importance of nanotechnology, it has been constituted various groups of students, consisting of (as key-roles): 1) physicists; 2) doctors; 3) biologists; 4) chemists. The groups will have to decide on the advisability of applying of nanotechnology in the actual society context.

2. Introducing the major questions

The questions are submitted for discussions: ***What is nanotechnology? What is nanobiomimicry? How it can influence our life and what could be its application?***

3. Documentation, identifying major arguments and presentation of the groups' conclusions

Each group must proceed to a documentation activity about how nanotechnology and its application are copying the patterns of the nature, what are the advantages and disadvantages of its use (from the perspective of the physicist, doctor, biologist and chemist).

The students from each group must share interesting facts and ideas found in the documented text, in order to arrive at a better understanding of the analyzed documents. It is recommended to start the documentation from the experiments proposed in the *Virtual Lab* of the *NTSE Project* (http://vlab.ntse-nanotech.eu/NanoVirtualLab/), especially: ***Understanding Nanoscale*** and ***Lotus Effect***. The documentation must be made also using the *NTSE Repository* (http://ntse.ssai.valahia.ro/).

Each group prepares and then reads its *Report* carefully, and underlines or quotes the facts and ideas which they consider as important, or interesting arguments that motivates the groups conclusions.

Each group of students shares the presented arguments, and identifies the most powerful pro-arguments (to be discussed), but also the cons-arguments (to be also debated). Inside the group, each student can use what he/she was learning about the subject, his/her own documentation and presents his/her own opinion about the topic. Each group must submit, in turn, the agreed position, and consequently, as responsible citizens, should have a voice in a real case, in the civil society.

RESOURCES

Procedural resources:

- methods and processes: *SAC* Method (*Structured Academic Controversy*), deliberations, conversation, observation, explanation, exercise, discussion;
- form of organization: groups, individual (frontal).

Material resources: video-projector, flipcharts, media texts, PCs, Internet

PROCESS FINALIZATION

For finalizing the didactic process, sets of questions are proposed. Each group must proceed to a documentation activity about how nanotechnology and its application are copying the patterns of the nature, what are the advantages and disadvantages of its use (from the perspective of the physicist, doctor, biologist and chemist). The students from each group must express their personal opinions, answering to the following specific questions:

- Which were the most powerful pros arguments?
- Which were the most powerful cons arguments?
- What areas of consensus were established?
- What consequences may result in the application of nanobiomimetics for human health, environment and society?
- Why this issue is important for a democratic society?
- Have you changed your opinion after the discussions? Why?
- Have you learned anything new from this lesson?
- What you have learned (specifically) from your colleagues?
- What would you like to learn more?
- From where did you get the information?
- Was your opinion adopted by the group?
- Which were, however, the areas of consensus in your group?
- How do you link the conclusion of the lesson with your quality as responsible citizen?
- What I should do if I were a person with responsibilities?

Important: the last part of the activity becomes very important, due to the fact that it represents a "debriefing" of everything the student has learned and lived during the whole process. The proposed questions dedicated to students substantiate in fact, the activity objectives.

ASSESSMENT SUGESTIONS

The evaluation of the students has to take into consideration the following items:

- understanding of the proposed / introduced concepts and terms;
- quality of retrieved information and investigation;
- clarity in the presentation of the selected information;
- active participation in various stages of the work;
- power of argumentation;
- justification of presented opinions;
- quality of final presentation;
- compliance with the proposed deadlines.

IMPACT ON STUDENTS

- using their real life perception and own life-experience as children / teenagers (especially linked to their knowledge);
- acquiring the necessary skills and capacities in their new quality: as active responsible citizens;
- maximizing the level of their involvement in the proposed topic;
- being eager to express their own opinions related to civic issues and to present their findings within the group and to the whole class;
- being capable of gaining a deeper understanding of the current socio-scientific issues;
- better communicating with teacher and colleagues;

STUDENTS' FEEDBACK

Expressed feedback:

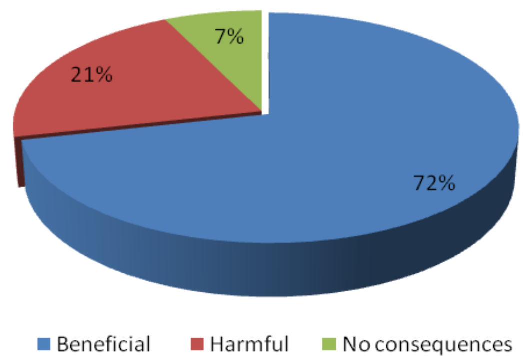
- real and actual issues have been discussed;
- opportunity to work in groups and know better the colleagues;
- possibility to express own opinion on certain issues;
- possibility to communicate without fear with the colleagues, and also with the teacher;
- proper frame to argument the own opinions, as well as listening patiently to others;
- opportunity to compile documents and find out things that otherwise are not so easy to know.

All students declared that they learn something new during the activity. They were motivated and very interested to the presented / discussed subjects.

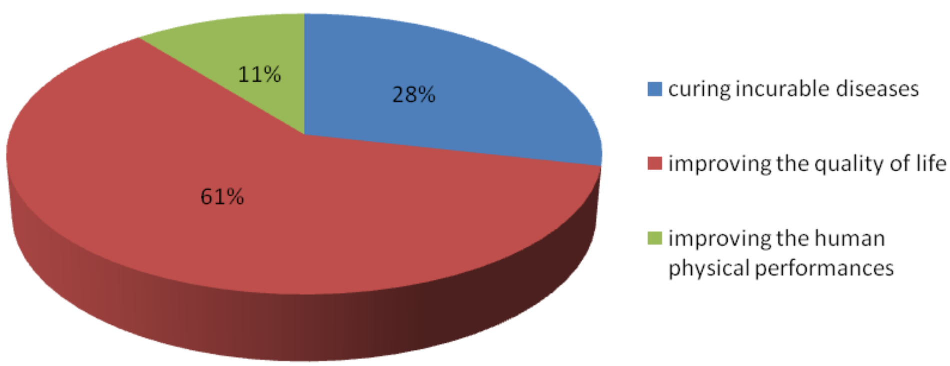
Processed feedback (graphical results):

Students were invited to fill in a questionnaire, in order to design a graphical feedback after processing their answers. The results are illustrated in the following diagrams.

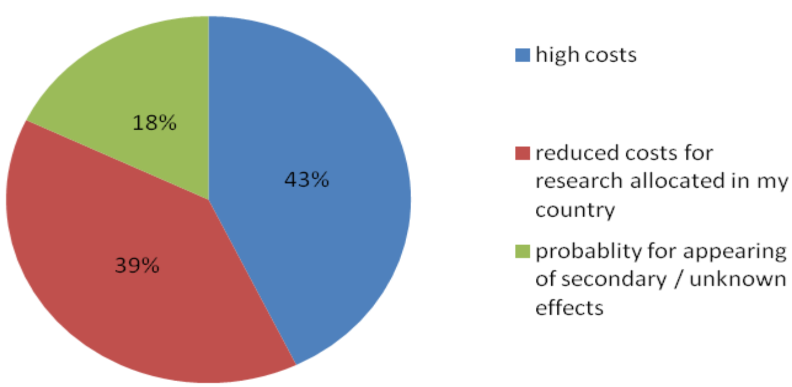
Considering the consequences of using nanotechnology

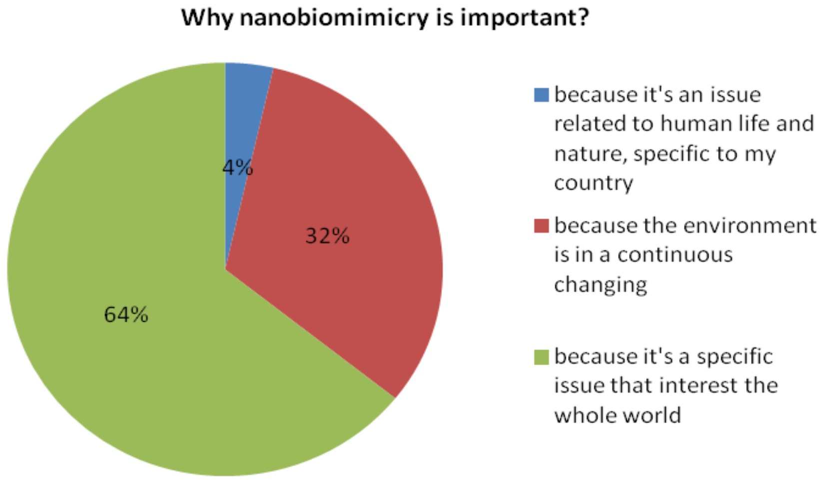


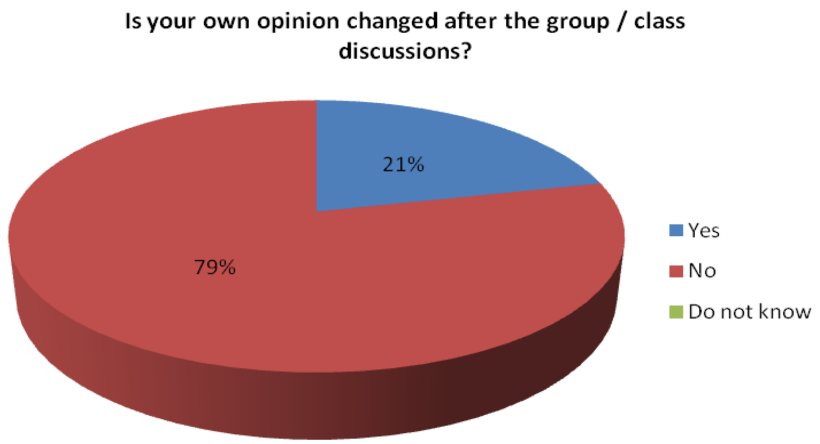
Expressing pros-arguments in developing and applying of nanotechnology

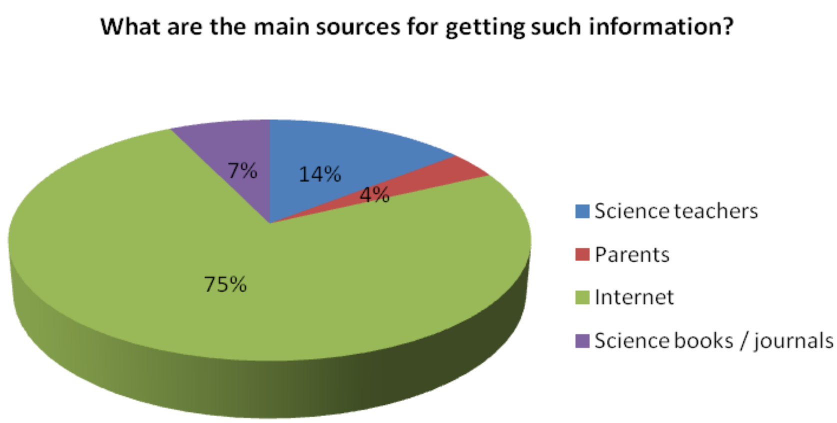


Expressing cons-arguments in developing and applying of nanotechnology




Why nanobiomimicry is important?
4%
32%
64%
because it's an issue related to human life and nature, specific to my country
because the environment is in a continuous changing
because it's a specific issue that interest the whole world


Is your own opinion changed after the group / class discussions?
21%
79%
Yes
No
Do not know


What are the main sources for getting such information?
7%
14%
4%
75%
Science teachers
Parents
Internet
Science books / journals

CONCLUSION

During the proposed activity, the students were asked to effectively participate in the discussions, through direct exchanging of ideas and experience. All the lessons' objectives were achieved, first from the scientific point of view, and second, from the social perspective, contributing to the formation of young people as unique individuals, able to discern and to take responsible decisions.

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Videos

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http://www.ted.com/talks/janine_benyus_biomimicry_in_action.html
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http://www.ted.com/talks/robert_full_on_engineering_and_evolution.html
http://www.youtube.com/watch?v=ACwKrJm7G0U
http://www.youtube.com/watch?v=iXcfm10bvZo
http://www.youtube.com/watch?v=LJtQ6dvcbOg
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Links
http://en.wikipedia.org/wiki/Biomimicry#Additional_examples
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Images taken during the activity