**Challenges of Teaching Nanochemistry**

**5.1 Introduction**

**5.1.1 Nanoeducation – New Approaches to Teach Chemistry**

Along with the challenge of the emergence of new viruses, as we have seen with COVID-19, humanity is rushing towards an ecological disaster. Climate change trends have been observed around the world in recent decades. This is reflected in changes in average temperatures worldwide, shifts in rainfall regimes, and increasing frequency and intensity of extreme weather events. These trends may have an impact on many different areas of the economy, ranging from water economy, agriculture, public health, coastal conservation, energy, biodiversity and more. Climate change affects the availability of clean water, as well as life-saving drugs, and international security. As technology advanced in the last century, the field of engineering has found itself at the base of modern science and it touches every field of science from biology to astrophysics.

Nanotechnology is an evolving field. It is an interdisciplinary science whose potential has been widely noted for over a decade.[[1]](#endnote-2) Despite significant private and public investment, progress in transferring nanomaterials from the industrial production lab has been slow and difficult. Two challenges that have slowed development have been a poor understanding of the new dangers posed by nanotechnology and the lack of appropriate policy for managing new associated risks. Scientists, engineers and entrepreneurs, on the other hand, continue to move forward, facing a variety of challenges: technical, regulatory and everything in between. Just as the concepts of nanoscale invention have required new insights from scientists, they also require new approaches to managing, producing, financing and deploying new technologies into the larger chemical industry. In this case, there is an extraordinary opportunity to use scientific, engineering, and policy knowledge to design new products that are as beneficial as possible to human and environmental health.1

Amazing scientific developments have happened in the 21st century that have left their “fingerprints” on our everyday life in several fields, especially technological and medical applications. The continuous and meteoric advances of nanomaterial science and its unprecedented application in nanotechnology-based consumer products indicate that nanomaterials are crucial for the development of new applications such as: biological labeling, diagnosis and medical treatment, solar energy harvesting, catalysis, and electro-optical applications. Considering the expected economic and societal impacts of nanotechnology products, one can predict that industrial use of nanomaterials will continue to grow significantly in the future.[[2]](#endnote-3)

One of nanotechnology's biggest challenges is education, which is considered a bottleneck for development and implementation of the field.[[3]](#endnote-4) Exposing students to nanotechnology and promoting nanotechnology awareness may help educators who incorporate nanotechnology into their curriculum to highlight the more socially relevant aspects of nanotechnology that may be of interest to students, such as how nanotechnology can improve society. It is important that educators integrate nanotechnology into the curriculum in meaningful and relevant ways so that students are more involved and exposed to nanotechnology.3

Lack of exposure to the field of nanotechnology is problematic at a time when nanotechnology is becoming increasingly important in the engineering field. A study of Yolcu and Dyehouse in 2018 was designed to determine the perception of engineering students of nanotechnology.[[4]](#endnote-5) The findings were clear: student exposure to nanotechnology and awareness of nanotechnology were low, but their motivation to learn and accumulate knowledge regarding nanoscience or to develop a career in nanotechnology was extremely high. As this study demonstrated, engineering students have little exposure to nanotechnology in a classroom setting. Educators can leverage student motivation to learn more about nanotechnology by integrating information from the field into the engineering curriculum, thereby increasing exposure and awareness. Evidence from various studies suggests that engineering faculties need to amend their curriculum to emphasize nanotechnology education, given the prevalence and need for engineering graduates with nanotechnology training. The high levels of motivation to learn about nanotechnology among engineering students are encouraging.4

Nanotechnology applications are good candidates for being taught in the context of science education as they have clear connections to daily lives of students. In addition, nanoscience is interconnected to various aspects of research, society, and industry.[[5]](#endnote-6) According to relevant research, nanotechnology applications represent contexts that can make science in the laboratory more relevant, interesting, and meaningful to students in their daily lives. Teaching by using nanotechnology applications in the laboratory therefore provides students with an opportunity to learn how modern science laboratories work and can encourage students to think about a career in science.[[6]](#endnote-7)

Using a pedagogy in which the student is the central focus has resulted in an increase in engagement and continuous motivation among students.[[7]](#endnote-8) Research by Ulster in 2009 indicated that teaching in the context of biology and chemistry makes the content experiential.[[8]](#endnote-9) In addition, the use of a context-based learning approach influences student interest and motivation to study the sciences.[[9]](#endnote-10) Nanotechnology education programs have evolved in many parts of the world, from core concepts in science and it supports research-based learning.[[10]](#endnote-11)

Nanoscience education is still evolving by leaps and bounds. Unlike other areas of science education, there are some gaps that need to be filled regarding how to teach key and crucial ideas of nanoscience in general, and especially nanotechnology.5 New developments in nanoscience education materials should be promoted. Additionally, research on how graduate students best learn nanoscience concepts should be undertaken in order to understand how to successfully teach the basics of nanometers and nanotechnology.10

Education is considered a bottleneck for the development and implementation of nanotechnology (REF). Research has contributed greatly to the education of nanotechnology by designing a wide range of innovative documentaries that assist higher education students in learning the basic concepts of nanoscience and the latest advances in nanotechnological development.

**5.2 Disseminate Nanoscience to Society**

Sebastian and Gimenez prepared YouTube documentaries in order to introduce the scientific activities of nanotechnology to society.[[11]](#endnote-12) The objectives of the proposed content focused on transferring knowledge generated in the field of nanotechnology and promoting scientific culture and innovation among public objectives. The results of their research showed that watching documentaries on YouTube enabled a quick and effective understanding of complex concepts related to nanoscience and nanotechnology.

Online videos and hands-on experience are considered useful in science. They are especially useful in laboratory demonstrations, or to present physical and chemical phenomena that may be transmitted more efficiently.[[12]](#endnote-13) The widespread use of websites, images, and documentaries about science and laboratories along with the ability to share them through the internet has revolutionized the teaching of science, enhanced our ability to discover new things, and offers new educational opportunities.[[13]](#endnote-14)

Videos are a valuable learning tool because they can be used to show students things that would have been difficult to convey otherwise. They can be particularly useful in constrained time periods like that of the global COVID-19 pandemic in the years of 2020-2021. In fact, a growing number of scientists and researchers are using videos to present their results at scientific conferences and meetings, during lectures, or in their publications as complementary online material. It seems clear that the use of films to understand the concepts and phenomena that take place in a world far below human scale, can facilitate the teaching of nanoscience.13

Based on obtained results, student evaluations, as well as YouTube indices, it has been concluded that advanced documentary films about nanotechnology help to facilitate student understanding of complex concepts associated with nanoscience and nanotechnology. In addition, public opinion after watching relevant YouTube content was found to be very positive and this shows that YouTube may be an important channel for the dissemination of nanoscience to society.11

The main goal of the research performed by Sebastian and Gimenez in 2016 was to contribute to nanoscience and nanotechnology education by designing and preparing a wide range of innovative certificate videos called Nanotechnology Capsules.11 These videos were designed to help higher education students learn basic concepts of nanoscience, nanotechnology, and the latest advances in these fields. Nanotechnology Capsules were categorized into three main fields at the nanoscale: nanomaterials and applications, promising nano fields, and biomedicine and sensors.

The future of innovative topics in the field of nanoscience and nanotechnology ranges from the properties of nanomaterials to their social effects. In addition, Nanotechnology Capsules sought to disseminate the scientific activities of nanoscience and nanotechnology into society. In this sense, the secondary objectives of the proposed approach for nanoscience and nanotechnology activities focused on two aspects. The first aspect was to focus on knowledge transfer generated in nanotechnology. The second aspect was to focus on the promotion of scientific culture and innovation in nanoscience and nanotechnology into public objectives.

Sebastian and Gimenez’s work was conducted at the University of Zaragoza, Spain, during two academic years (2014 to 2016).11 The study involved 25 graduate students in chemical engineering who participated in a nanomaterials course and 85 other people with differing levels of education (high school through doctorate). The study consisted of three parts. In the first part, a selection of advanced research topics for writing scripts of nanotechnology capsules and a digital recording were chosen. The second part consisted of exposure of nanoscience to society and a method of study for nanoscience. Exposure was administered through public media, radio, and the written media. How the teaching methodology affected student learning through two different teaching methodologies was also examined. The first methodology was a traditional technique using a PowerPoint presentation to teach the basic scientific principles that guide the participants through the unique properties of nanoscience. The second was a method based on Nanotechnology Capsules where students learned through visual media prepared specifically for the study and then they were asked to perform a list of activities and answer questions. The third part was a student survey and evaluation. Post-exposure public opinion was very promising and showed that YouTube and documentaries were an excellent channel for disseminating nanoscience into society.

**5.3 Green Nanotechnology**

Recently, nanomaterials have received significant attention for environmental and energy applications because of their small size, high surface area, well-defined structure, high dispersion and high reactivity. Nanotechnology has considerable potential in providing new and improved solutions to many great challenges facing society today. Green nanotechnology offers opportunities to obtain desirable materials with low toxicity and cost, high chemical and thermal stability, and high degradation activity for environmental repair.

Many nanometer materials such as titanium dioxide, zinc oxide and iron oxide have been synthesized through various techniques. These nanomaterials have been used for air purification, water treatment, soil and sediment cleaning, and cleaning hazardous waste sites. In addition they have been used in the treatment of sensing and monitoring environmental pollutants such as toxic organic compounds, paints, pesticides, volatile organic compounds, harmful gases, and bacteria in various media (REF).

Many of the current challenges facing humanity can only be solved through science and engineering. Recently a new concept called green nanotechnology has emerged. Green nanotechnology is the use of nanoscale technological means to enhance and improve existing technologies so that they preserve the environment and natural resources. The goal of green nanotechnology is to reduce, as much as possible, environmental pollution resulting from technological processes that pose a risk to human health using environmentally friendly technology. The integration of nanotechnology in green technologies is the basis for the development of the concept of green nanotechnology. Climate change, scarcity of fossil fuels, and dilution of natural resources are some of the largest environmental challenges of the 21st century. The basis for the development of green nanotechnology stems from the importance of integrating this field into industry and daily life. This allows green technology to be part of the array of potential solutions to address environmental challenges. Recognition of this opportunity has led to the development of the “Green Nanoscience” concept.

**5.4 Nanogreen Education**

The environment persists as a hot topic throughout the history of nanotechnology. Yet despite decades of research, definitive conclusions on the environmental impact of nanoparticles remain inconclusive. Nanoparticles can provide great advantages for applications such as monitoring devices and drugs. Due to their small size, particles with nanodimensions can access places that may otherwise be difficult, if not impossible, to reach. Nanoparticles also have a particularly high surface area per unit volume, often with a high number of edges, which can help catalyze chemical reactions and allow high-sensitivity detectors. Finally, size-related effects produce very interesting physical properties. Whether electronic, optical, thermodynamic, and/or mechanical, these properties are unique to nanomaterials and they are not observed in bulk materials. These features can be tuned for optimal performance in a given function through small adjustments in size, shape, or composition.

Nanotechnology continues to offer the creation of new materials and applications that will benefit human society. However, there is growing concern about the potential health and environmental impacts of manufacturing and using nano-products that have permeated into everyday life. Hundreds of studies have reported nanomaterial hazards, due (to a large extent) to the complexity of nanomaterials. There have been cases where there was no consensus on the impact of these hazards and thereby this raised societal concerns. This brings into focus the need for research that addresses the applications and implications of new nanomaterials. Scientists play a key role in investigating these potential nanomaterial hazards as we move from understanding to minimizing them. Greener nanosciences are presented as an approach to determine and implement design rules for safer nanomaterials as well as safer and more efficient processes.[[14]](#endnote-15)

A sense of responsibility towards the Earth has challenged many research groups around the world to further explore the subject of green nanotechnology. Efforts to develop alternative synthesis methods that produce more consistent products and that do not rely heavily on toxic substances and extreme synthesis conditions have also led to other benefits. For example, for many years reducing silver ions from solution was the preferred approach to their synthesis, but this often meant using toxic reducing agents and surfactants to cover precipitation growth of a certain size. For decades researchers have identified the potential uses of silver nanoparticles. Their applications range from microbial coatings to next generation plasmonica and electronics.

In 2009 researchers from Poland developed an alternative strategy that uses fungi as a reduction factor. They reported that microorganisms exposed to pollutants in the environment, such as metal ions, have a powerful ability to fight this metal stress. Their research focused on the fungal genus Penicillium. Penicillium is from a family of fungi from which the common antibacterial drug penicillin is derived. They performed a series of experiments where they immersed fungi extracted from the soil into a silver nitrate solution. The researchers concluded that silver ions would trap onto the surface of the fungus where they shrank and slowly formed silver particles. As this approach is environmentally friendly and easy to manage it became a part of the growing movement towards biological synthesis.

In recent years, many researchers have developed and researched plant extracts as additional "green" means of synthesizing nanomaterials at a faster rate than what is possible with fungi. In 2018, researchers used *Cinnamomun verum* and *Vanilla planifolia* (sources of the familiar cinnamon and vanilla flavors used in cooking) as reducing agents and as a covering tool for the production of iron nano-oxide particles that could be used in hyperthermia treatments for cancer.18 The researchers emphasized in their study that the method eliminated the need for lengthy procedures to separate the product from any harmful chemicals used in its production – a significant advantage for nanomaterials used in medicine. Of note as well is that the method minimizes harm to the environment.[[15]](#endnote-16)

* 1. **Drug Delivery Nanotechnology - The Medicine of the Future**

Nanotechnology has been used for innovative scientific endeavours for decades. As our ability to build tiny molecular machines improves, so do the applications of these ground-breaking technologies in the fields of energy, textiles, and medicine (NAS, 2002).[[16]](#endnote-17) Nanometer scale materials, which are billionths of a meter in length, offer the medical world a huge advantage. Many of the medical conditions that humans experience result from processes that occur at the cellular level. To treat them it is necessary to use substances that are small enough to enter into the bloodstream and penetrate the cells. They must then cure the defective processes that cause the disease.[[17]](#endnote-18)

Professor Richard Smalley, winner of the 1996 Nobel Prize in Chemistry for discovering a nanoscale carbon form resembling a tiny hollow football, aptly described the vision behind the field:

Human health has always been determined by the nanometer scale. This is the scale by which the functions and features of the life machines operating within each cell in each living creature are determined. The practical impact of nanoscience on human health will be enormous. Indeed, nano medicine has enormous potential: the field offers more sensitive, effective and convenient diagnostic methods, better quality imaging, implant protection and prevention of infections, and of course the destruction of disease agents, such as cancer cells, bacteria or viruses.[[18]](#endnote-19)

Drug delivery technologies are designed to ensure that a particular drug will only reach and act on specific predetermined cells. Thus, the drug does not disperse in the body randomly and much lower doses can be administered. Sometimes it is even possible to reuse effective drugs that have been banned for use due to side effects caused by their wide-spread dissemination into the body. Because of their enormous potential this is a very active field of research and many technologies and methods have already been developed to achieve the goal of targeted drug delivery. In one technique, the drug is loaded into a spherical particle about 100 nanometers in diameter. The surface of the particle is decorated with biological components that allow it to escape the body's immune system and integrate unhindered into the bloodstream (Patra et al., 2018).[[19]](#endnote-20)

The process of drug delivery consists of various engineered technologies for targeted and/or controlled release of therapeutic agents. Traditionally, the main method of delivering drugs to a desired area of the body has included pills taken orally, eye drops, ointments, and intravenous solutions.19 Later, more sophisticated approaches using polymeric materials (hydrogels and fibres), vesicles (liposomes and micelles), and chemically modified drugs have been introduced to achieve more target-specific delivery.[[20]](#endnote-21) In recent years, with the advancement of nanotechnology, major developments have revolutionized this field. Now, nanoparticle and liposome loaded drugs can precisely target specific regions or organs in the body. However, challenges remain as most of these new technologies fail to reach clinical expectations. Novel approaches inspired by nature could provide alternative solutions and lead to precise and sustainable drug delivery practices.20

One of the major contributions of the "nano" revolution in medical fields is the development of nanoscale systems that can carry drug molecules in the body. Unlike the conventional carrying systems that are not nanoscale, like tablets and pills, nanoscale systems can penetrate a specific area in the body, such as a cancerous tumor. To transport the particle to the target cells of the drug, a series of chemical reactions allows for antibodies to attach to the layer that surrounds it.[[21]](#endnote-22) Their chemical coding allows them to act only on cells that have a receptor with a complementary chemical code. This chemical code is a specific type targeted for delivery, assuming the rest of the body cells do not express that receptor. As the particles enter the cell, proteins inside it break down the protective layer and allow the drug to be released directly to where it will be most effective.21

The ability to load a wide variety of drugs into nanoparticles and to control over where the drugs will be broken down offer a huge improvement in drug efficacy. This way the side effects are reduced, and new, non-conventional combinations of complementary medicines or cocktails can be created.21

Abu-Much et al. developed an interesting lab activity which aimed to load drugs into nanostructures for specified drug delivery.[[22]](#endnote-23) Liposomes are bubble-like structures made of phospholipids, molecules that have a polar head group and hydrophobic tails. These molecules have a unique mode of dissolving in water: They spontaneously organize into liposomal forms with a hydrophilic interior part surrounded by a hydrophobic ring. The molecular shape of phospholipids and their amphipathic chemical structure reflected by a polar head and two long non-polar tails are responsible for their special mode of dissolving in aqueous environments. Phospholipids create a circular "bilayer sandwich" style arrangement. Their hydrophilic heads face two watery environments, the interior part of the liposome structures, and the aqueous dispersion medium. Their hydrophobic tails are confined in a middle region between the interior and exterior aqueous phase which thereby create a hydrophobic ring between the two hydrophilic head layers.

Upon comparison, the structure of liposomes is similar to a cell membrane. Cell membranes are a barrier that separate a cell from its surrounding environment; they are composed from phospholipid molecules in addition to other components like carbohydrates and proteins. In the basic structure of a cell membrane, the phospholipids are arranged in a double layer called the "lipid bilayer" where the two strings of the hydrophobic tails are kept away from an aqueous environment. Being cylindrical, cell membrane structures are a mirror image of liposome structures.[[23]](#endnote-24) In medicine, liposome structures have an interesting application as nanocarriers to deliver drugs. The unique structural features of liposomes are the entrapment of both hydrophilic and hydrophobic compounds; their structural similarity to a cell membrane; and their biocompatibility. These properties make them one of the most important candidates investigated as a vehicle for drug delivery available today.[[24]](#endnote-25)

Abu Much et al. presented a laboratory activity based on using phosphatidylcholine as a natural phospholipid.22 Phosphatidylcholine is easily extracted from a variety of readily available sources such as egg yolk or soybeans. Phosphatidylcholine is a major component for "designing" a drug nanocarrier based on liposome structures. The liposomes were used as a microscale drug carrier and were transferred to nanometer scale by the use of a simple apparatus called the Avanti® Mini-Extruder apparatus. Phosphatidylcholine is a typical membrane phospholipid which contains a charged head consisting of a negatively charged phosphate and positively charged choline. They are attached through glycerol to two hydrophobic fatty acid tails. Vigorously shaking a mixture of phosphatidylcholine and water results in the formation of liposomal microscopic spheres.[[25]](#endnote-26)

The detection of microscale liposomes was based on using an optical microscopic system connected to a camera. This process led to the exploration of the possibility of a drug solution which could penetrate into the hydrophilic interior part of the liposomes. Aqueous drug solutions were dyed with a hydrophilic food color in order to detect it inside the liposome structures. In the second step of this laboratory activity, the drug-loaded liposomes were converted from microscale to nanoscale using a simple apparatus called the Avanti® Mini-Extruder. In short, the solutions of liposome structures were passed through nanometer-scale membranes and converted to nano-liposome structures.22 Consequently, the solutions were gradually turned from turbid to more transparent as a function of the number of passes through the mini-extruder membrane. The Tyndall effect was employed in order to distinguish between the microscale and nanoscale solutions. This was done via passing a laser beam through the different solutions and detecting the difference in light scattering.[[26]](#endnote-27)

Drug delivery is considered one of the most highly researched subjects owing to its importance in medical advancement. A group of 25 pre-service teachers from the Academic Arab College for Education in Haifa, Israel, participated in these laboratory activities as part of the course Chemistry in the Lab.22 The laboratory activities described here provided cheap, simple, and interesting ways for engaging students in new modern science fields like nanotechnology. For this purpose, liposome structures and their chemical nature were used as teaching model. The teaching model involved students comparing the chemical structure of a cell membrane and the liposomes.

The laboratory activities were associated with an introductory lecture where different concepts were discussed. Implementation of such projects can affect student attitudes towards chemistry and encourage them to perform these important laboratory activities during their teaching in the future. which will lead to a significant change on the subject of nano-liposomes and "drug vehicle transport" in chemistry classes. The importance of this research lies in the fact that the students were the ones who perform the activities and they learned through practice. After the completion of the laboratory activities, the students noted the results, analyzed them, and they presented their conclusions. From this they could relate them to theoretical and daily life.22

In addition, many other technological fields are being developed. These fields include materials and systems that simulate cellular systems so that we can conduct biological research based on tiny devices. Other groups are working to develop an ideal environment for growing cells and for 3D printing of tissues outside the body. These efforts are done with the hopes that in the future we can implant such tissues and possibly even artificially grow whole organs in the human body.

* 1. **Using Nanotechnology to Fight Cancer**

One of the great challenges facing the world of medicine and biology today is finding effective treatments for cancer. Despite new developments and encouraging progress in many areas, most standard therapies suffer from a major fundamental problem – their lack of specificity. Although radiation and chemotherapy effectively destroy cancer cells, they also damage normal cells. The result can be severe, life-threatening side effects.[[27]](#endnote-28)

Nanotechnology is involved in attempting to address this struggle through a multitude of developments implemented in various stages of clinical research. In some cases, nanostructures are mainly used to help inject and transport anti-cancer drugs into the bloodstream. More sophisticated methods adorn the surface of nanostructures with receptors that allow accurate delivery of drugs to specific cells. Sometimes they also manage to add a remote-control operating mechanism so that the nanostructures go into action only in response to an external factor that excites them.[[28]](#endnote-29)

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In one method, nanoparticles can target an infected area using a variety of techniques. The chemical and physical properties of the substance are then exploited to destroy the cancer cells. To do this, radio waves or infrared waves that are not harmful to humans are projected onto the area. The nanoparticles absorb the energy of the radio waves and emit it in the form of heat that spot-burns the diseased cells.[[30]](#endnote-31)

* 1. **The Use of Nanotechnology in the Destruction of Bacteria**

One of the earliest uses of nanomaterials in medicine is their potential to be used as an antibacterial substance, *i.e.,* they can kill bacteria. Studies have found that nanoparticles from certain substances, especially silver and zinc oxide (ZnO), have antibacterial properties.[[31]](#endnote-32) They harm bacteria through a variety of mechanisms. Active chemical forms of these types of nanoparticles are formed on the surface of particles. These nanoparticles then act upon the cell envelope of the bacterium and cause irreversible damage that eventually leads to bacterial death. The use of zinc oxide nanoparticles has been proposed as a possible solution to a serious problem in hospitals in the modern world, the development of antibiotic resistant bacteria. Hospitals have conditions that allow bacterial populations to thrive. Consequently, some bacteria are developing improved resistance to standard antibiotics. Antibacterial nanoparticles work through different mechanisms to kill bacteria in comparison to traditional antibiotics and they are therefore more ideal candidates for preventive treatment against these resistant bacteria.31

Gadenken developed an efficient way to infuse nanoparticles into textiles on an industrial scale. This would allow the nanoparticles to continue killing bacteria even after multiple washes at high temperatures.[[32]](#endnote-33) From these antibacterial fabrics it is possible to produce bedding for hospital beds and uniforms for medical staff. These nanoparticle-infused fabrics could help hospitals lessen infections that endanger patients.

Another example of using the antibacterial capabilities of nanoparticles can be found in the treatment of body odor. The source of the sour and unpleasant smell of sweat is not from the sweat itself, but from the secretions of bacteria that feed on it. To this end, many deodorants contain silver nanoparticles which kill the bacteria in odor-prone areas such as the armpit and thus prevent bad smells.[[33]](#endnote-34)

The same idea is also used by textile companies, which infuse nanoparticles into their fabrics, especially in the production of socks.[[34]](#endnote-35) Following this, there are now socks in clothing stores that prevent the accumulation of bacteria and foul odors on feet. Such socks have been warmly adopted by armies around the world as soldiers often operate in field conditions and cannot take off their shoes or change their socks for long periods of time.[[35]](#endnote-36) Accumulation of bacteria in army shoes over time can cause infections that impair the soldier fitness. Antibacterial socks can provide a perfect solution to this problem.[[36]](#endnote-37)

**5.8 Nanobiomimicry Education**

**5.8.1 Introduction**

Nature has long been a source of inspiration for designers and engineers in their quest to solve many of humanity’s problems. Increasingly, in the industrial world, nature is seen as a model and a reference point. Biomimicry is the name given to nature inspired innovation that seeks sustainable solutions to human challenges by emulating nature's time-tested patterns and strategies.[[37]](#endnote-38)

~~Definition of Biomimicry~~ The word biomimicry means the imitation of life and it comes from a combination of the Greek words “bios,” which means life, and “mimikos,” meaning imitation. In 1962, the term biomimicry was first used as a generic term that referred to cybernetics as well as bionics. Bionics is defined as ‘‘an attempt to understand sufficiently well the tricks that nature actually uses to solve her problems.’’ Bionics is closer to the meaning of “biomimicry’’ as it has been used by scientists since the 1980s. In fact, the term bionics was used earlier to refer to technology that imitated nature until the coining of the term biomimicry.37

The core idea is that over the course of thousands of years of evolution, nature has already perfected solutions to many of the problems that humankind is grappling. Biomimicry holds tremendous potential to inspire eco-friendly designs in technology at this critical point in human history. Biomimetics is a multidisciplinary field that involves design and manufacturing of various commercial materials and apparatuses based on the biological function and structure of different objects and organisms found in nature. Biomimicry refers to studying nature’s most successful developments and then imitating these designs and processes to solve human problems.37

**5.8.2 Nanobiomimicry - From Nature to Nanotech**

Imitating the characteristics of living things opens up a whole world of innovation and entrepreneurship. This also bolsters the values of nature conservation and sustainability. In biomimetic eyes, these values take on practical meaning, even through life. The assimilation of the biomimicry industry in education and teaching looks promising.

Man has always observed nature, but only around the 1970s did this issue enter the field. Over the years, technologies such as electronic microscopy have been developed that enable the identification of biological structures at the nanoscale. Computerized modelling capabilities have been developed that allow for the study of organisms and a better understanding of their work, as well as the transfer of knowledge to application. In a famous example, the source of the skeleton which was a model for the locomotive design of the high-speed Japanese train, where without modeling capabilities it was impossible to copy the shape of the source on all its parameters and to the locomotive model. Similarly, without the ability to examine at the nanoscale level, microscopically, they would not understand the leaf structure of the lotus flower. The lotus flower is a model for producing water-repellent surfaces and dirt. Nor would they know the structure of shark skin that inspired the development of suits for swimmers.

What might be a goal in teaching biomimicry in schools? First, it is an excellent field through which to teach, strengthen, and practice STEM skills. From the responses in the field we know that biomimicry studies are a very attractive environment for students: It presents an opportunity to explore and invent as well as promote innovative and entrepreneurial thinking. Another goal of biomimicry teaching is to impart value. Values ​​of nature and environment are inherent in the work. For example, biomimicry studies can teach students to value species diversity. It is customary to say that, "every extinct species is a lost teacher." Nature is not only a storehouse of materials but also a storehouse of knowledge and insights via respecting nature, observing nature, and finding a different view of nature. In this way an optimistic approach can be sought out in an environmental context. Instead of scaring students (*e.g.* “save water or else the water in the Sea of ​​Galilee will run out,” or, “save energy because we will run out of energy resources”) one can explain to students that there are solutions out in nature: let us all go and learn from them. There is much more optimism in this field when dealing with environmental issues.

Several trends can be identified in the development of the field of biomimicry. The first is the imitation of shapes and structures and their related functions, usually at the macro level, and their copying to other places. For example, VELCRO® is a material that is familiar to everyone. Its technology is based on the structure of lugs, which are derived from plant seed structures, and they attach to loops which are similar to animal fur structure. The aforementioned Japanese train is another example and an additional example of this is the German pesto company. This company is involved in developing robots and has a permanent department that deals with biomimicry. The third trend in biomimetic development includes developments at the nano level. This involves imitating shark skin, lotus leaves, or gecko feet. Taken together the trends can be summarized as when we accumulate biological knowledge, our technologies evolve.

The theme of biomimicry is the imitation of the best ideas from nature and the use of nature as an inspiration to solve human problems. In recent years, there has been great progress in the field of nanotechnology in the field of biomimicry.

Learning objectives:

* Understand that biomimicry is an imitation of nature's best ideas for solving human problems. Think of things in nature that we can use as inspiration for solving a human problem.
* Understanding that nano means “really small. So small that you cannot see it. Things behave differently when they are so small. Nano-sized things are found in many places, including in nature and many nanotechnologies have been inspired by nature (biomimicry).
	+ 1. **LED lighting Biomimicry**

Most of the applications developed in the past have been created on the macromolecular level. Only recently have the biomimetics begun to approach the micro and sub-micro molecular level of matter.[[38]](#endnote-39) At the turn of the century, however, the interests of scientists and researchers have shifted towards thinking of matter at the atomic level, hence leading to the field nanotechnology.

The unique nanostructured surfaces in nature are manifested in many applications and in varied ways: the surface of shark skin is endowed with antibacterial capabilities; the nonstructural structure of butterfly wings which imparts spectacular colors; the surface of the lotus leaf which allow it to self-clean; the surface of a firefly’s belly cuticle which increases effective light distribution; and more. The imitation of nonstructural materials enables not only the development of innovative applications but also environmentally friendly applications that are highly efficient in the utilization of material or energy.

A team of researchers from South Korea developed more efficient and inexpensive LED lighting.[[39]](#endnote-40) The researchers hoped that researching the structure of a firefly's illuminating organ and imitating it would make further advancement possible. Other than fireflies and various illuminating beetles, it is claimed that 90% of animals that exist in the depths of the sea produce light at some level. The creation of light by animals serves different purposes: camouflage in certain living environments; attraction of prey or mates; rejection; and communication between different individuals. The creation of light by organisms, bioluminescence, is the result of an efficient chemical reaction of turning chemical energy into light energy. In most cases, the pigment luciferin, which is oxidized by the enzyme luciferase to form the flash of light, is involved in the bioluminescence. In the firefly, flashes of light are made through this process, which takes place close to the firefly's abdomen.39

During the study, the researchers found that the cuticular structure (the outer layer of the insect) of the firefly's abdomen was composed of many layers in an organized structure. Using electronic microscopy and numerical analysis, the researchers found that the layer acted as an anti-reflective structure, which reduces light loss and increases illumination efficiency. The researchers created an artificial model that served as an LED lighting lens. The nanostructure structure of the new LED lens, inspired by the surface of fireflies, significantly increased the visible light transmission compared to ordinary, smooth-surfaced, antireflective coatings.39

* + 1. **The Clinging Secret of the Gecko**

Is the day close when humans will also be able to climb walls like a gecko does? The secret to a gecko’s gravity-defying grip turns out to be the rows of tiny hairs, called setae, on their toes. The hairs cling to any surface using via sticky Van der Waals forces, which only work at microscopic scales. The advantage of this is a reversible, strong grip, one which does not require the need to deposit an adhesive.

The gecko can stick to smooth and steep surfaces and detach its foot from the surface in a split second without applying force. To illustrate, a gecko can hang onto a glass surface with one finger. In the past, scientists believed that the gecko secreted a sticky substance on its foot. However, it turned out that the gecko's ability to adhere to surfaces is due to these microscopic bristles. Scientists already knew that the tufts of the gecko’s tiny hairs get so close to the contours of surfaces that Van der Waals forces kick in. This type of physical bond happens when electrons from gecko hair molecules and electrons from the wall molecules interact with each other and create an electromagnetic attraction.

On the surface of the gecko's legs there are millions of tiny hairs made of keratin (a type of protein), which are a million meters long. Each hair splits at the end into sub-bristles which are several nanometers long. The bristles can bend and adjust to the tiny depressions that are on any surface. This fit creates molecular gravitational forces (specifically, Van der Waals forces) between the bristles and the surface to which they adhere. These forces are relatively weak, but their multitude creates a vast surface area that doubles these weak molecular bonds and creates a particularly strong cling. The gecko’s quick detachment is accomplished by lifting a small corner of the foot which causes a change in the angle of the hairs and eliminates the Van der Waals Forces. They are so small that they interact with whatever material the gecko is climbing at a molecular level. This phenomenon can be referred to as a natural nanotechnology phenomenon. Scientists and engineers learn about this natural nanotechnology and have developed new technologies by studying these wall-climbing abilities of geckos.

Geckos can stick to surfaces because their bulbous toes are covered in hundreds of tiny microscopic hairs called setae. Each seta splits off into hundreds of even smaller bristles called spatula. The gecko's foot has approximately 6.5 million hairs on. However, only 2,500 hairs are needed to hold the gecko's body vertically. If all the 6.5 million hairs on their legs were connected at the same time, they could carry a weight of approximately 130 kg.

Thanks to microscopic hairs (called setae) on their toes, geckos can stick to almost any kind of surface. These reptiles do not lose their stickiness over time. In fact, the more pressure they apply, the harder they stick to any surface. This mobility technique has inspired scientists to develop gecko tape – a skin-like, silicon-based material comprised of tiny synthetic hairs that can mimic the gecko toes stickiness.

Inspired by this attachment mechanism, "nano tape" (also called "gecko tape") was developed. It is a material covered with nanoscopic hairs that form weak intermolecular bonds and thus mimic the hairs found in gecko legs. The bonds formed allow flexibility so that at one moment the bond to the surface is very strong and at another moment the bond is loose. This linkage material is reusable, does not emit toxins and leaves no traces in the environment. This linkage material has many possible applications, from new types of car tires with better traction to robots that can walk on walls.

Glue is a natural or synthetic material that allows solid bodies to be attached to each other. The adhesives industry is highly polluting, and some adhesives emit toxic chemicals into the environment. Considering the above, it is necessary to develop adhesives that combine environmentally friendly and user-friendly materials which do not harm the quality of the product. It is important to consider what the ideal glue is. Ideally, it should be a substance which is strong, resistant to various conditions, effective over time, environmentally friendly, and easily removable. By turning to nature one can find inspiration for the development of a new linkage material precisely at the foot of the gecko.

In recent years engineers have managed to reproduce similar setae from silicone, leading to a myriad of variations of gecko-skin technology. Among them are a gizmo to allow humans to climb a sheer glass wall, robots able to pull objects hundreds of times their own weight, and grippers for space repairs.

* + 1. **Prevention of Air Accidents using Nanoparticles**

Accumulation of ice in aircraft systems is one of the common causes of air travel accidents. This problem also affects defense industries that operate reconnaissance aircrafts and drones. The most common method today to deal with this phenomenon is to apply solvents which change the freezing point and prevent baldness. At the same time, the high toxicity of these solvents is problematic and requires special consideration.[[40]](#endnote-41)

Recently a team of researchers has been able to develop a biomimetic approach to solve the ice accumulation challenge. They developed an advanced surface for metals and composites which causes ice accumulation to be reduced. The method they developed was found to be extremely effective in preventing baldness. The innovative method is based on nanoparticles that cling to the surface and create a "lotus effect." The lotus effect involves water droplets which slide off the aircraft surfaces, thus preventing the accumulation of ice. This effect is achieved by arranging the nanoparticles in the form of an “abandoned bed.” The abandoned bed is the space between the nanoparticles, so small that the droplets are unable to penetrate between them and therefore do not stick.40

**5.9 Biomimicry of the Lotus Effect**

When rain falls on lotus leaves water beads up with a high contact angle. The water droplets promptly roll off the leaves and collect dirt along the way. In recent years, this self-cleaning ability, or lotus effect, has stimulated considerable research worldwide in order to exploit it for a variety of applications. These applications range from self-cleaning window glasses, paints, and fabrics to low friction surfaces.

The lotus plant already possesses a mechanism for self-cleaning. Raindrops fall onto the leaves of the lotus flower, drip off them, and then they wash away the dirt from the leaves surface. In a way, the plant cleans itself. Since the lotus plant surface has a self-cleaning effect, it must be water-resistant (hydrophobic). On the lotus leaf, this water-resistant layer is composed of small wax crystals. Lotus leaves and nasturtium leaves are self-cleaning due to nano- and microscale structures and a waxy coating. Together these features create a super hydrophobic surface.

Due in part to the micro- and nanoscale structures of the lotus leaf and the air trapped in between, only two to three percent of a raindrop actually contacts the leaf surface. Today, thousands of buildings boast self-cleaning materials like paint, roofs, textiles, glass windows, and sprays, many of which have already sprung onto the market. But despite the development of these practical applications, scientists still have a lot to learn about the specific mechanisms behind self-cleaning – or the so-called “lotus effect”. The lotus – a type of water lily native to Asia – has had its praises sung for thousands of years. In religious symbolism, the Buddha often sits on a lotus leaf. Hindus view the lotus blossom as a symbol of divine beauty by associating the unfolding of the petals with the expansion of the soul. More recently, botany and nanotechnology have united to explore not only the beauty and cleanliness of the lotus leaf, but also its lack of contamination and bacteria, despite it dwelling in dirty ponds.[[41]](#endnote-42)

In recent years, scientists have developed theoretical models for the underlying mechanisms of the lotus leaf’s self-cleaning properties. Coupled with the leaf’s waxy chemical composition, the lotus leaf has two additional levels of structure which provides its self-cleaning properties – microscale bumps and nanoscale hair-like structures. The self-cleaning property of the lotus leaf – and applications derived from it – requires the surface to have roughness on two scales. When a raindrop falls on a lotus leaf, it forms a high contact angle of greater than 90 degrees. This means that it beads up rather than spreads out as a liquid with a low contact angle of less than 90 degrees would.

A lotus leaf can have a contact angle close to 170 degrees which makes it extremely hydrophobic. For reference, human skin is slightly hydrophobic with about a 90-degree contact angle. In fact, as mentioned above, as little as two to three percent of a raindrop actually contacts the surface of a lotus leaf due to the waxy composition of the leaf and to the air trapped between the raindrop and the leaf’s micro- and nanostructures.41 The effect of the nanoscale hairs has been isolated from the microstructure and chemical composition of the leaf. The results verify the importance of the nanostructure on the lotus leaf’s self-cleaning ability which is an essential understanding for inventors designing self-cleaning products in the future.

* 1. **Nanocosmetics - Cosmetics Containing Nanoparticles**

Nano-shaped material is a material whose particles are 100 nanometers or less. A nanometer is a unit of length with one million nanometers are equal to 1 mm. Nanoparticles are inadvertently formed and released into the atmosphere by many industries (such as by manufacturing plants), in domestic activities (such as cooking), and other daily activities (such as driving a car with a heat engine burning fuel). In addition, nanoparticles are now also deliberately produced for commercial, research and other purposes. Therefore, human exposure to nanoparticles has increased and the sources of them are diverse.[[42]](#endnote-43)

The use of nanotechnology has stretched into the field of cosmetics by taking the name of nanocosmetics. This widespread influence of nanotechnology in cosmetic industries is due to the enhanced properties attained by the particles at the nanoscale including color, transparency, solubility, etc. The different types of nanomaterials employed in cosmetics include nanosomic, liposomes, fullerenes, solid lipid nanoparticles, and others. Apart from the difference in size, nanoparticles are characterized by different properties compared to the same material that is not nano-sized. A need has arisen to test nanoparticle safety.42,[[43]](#endnote-44)

It is important to note that cosmetics are intended for use on whole and uninjured skin, not irritated, injured, unhealthy skin and the like, and this is especially true in products that contain nanoparticles.42,43 Due to their size, nanoparticles can penetrate the bloodstream through the skin in products that come in contact with it (such as creams), or through the airways in aerosolized products (such as aerosol deodorant). With nanoparticles that are insoluble and/or resistant to biodegradation there are also concerns about their accumulation in various tissues and organs. In addition, as a precautionary measure, it is not recommended for pregnant and lactating women, toddlers, people suffering from diseases, and/or the elderly to use products containing nanoparticles even if there is no explicit warning written on the product label.

The benefits of nanoparticle-containing materials depend on the type of component. For example, in a component that serves as a radiation filter, a higher level of protection can be achieved by using nanoparticles. In addition, you can achieve more pleasant and "transparent" textures when applied to the skin. Cosmetics containing nanoparticles are designed and tested for use on whole and uninjured skin.42,43

* 1. **Other Uses**

Nanotechnology has a variety of other medical uses. In the field of diagnostics, nanotechnology-based detectors make it possible to identify tiny amounts of substances that indicate an abnormal medical condition with a high degree of accuracy. These detectors can be easily carried on the body. This feature allows for continuous monitoring that can detect a variety of syndromes before they develop into a dangerous medical condition, when they can still be treated effectively. In the world of imaging, scientists are developing new materials that will work as biological markers and make it possible to monitor a patient’s physical condition along with tools such as MRI and sophisticated microscopes. This field is constantly improving and provides better imaging at a higher resolution, in a more focused and accurate way than ever before.

There are, of course, other new areas of research that will be developed in the future. These developments include using nanoparticles to capture hazardous substances. Others may be able to cover implants in a layer that prevents them from being rejected by the body. Or, other developments could include building nanobots that can perform specific tasks similar to proteins (body work machines). Sometimes it seems that the only thing that prevents other important breakthroughs in the interface between nanotechnology and medicine is the limits of our imagination and creativity. As with any subject that combines human beings and technology, economic and moral questions arise here that require attention, but there is no doubt that this is one of the most interesting, important and dynamic areas in contemporary science.

If you let your imagination wander for a moment in the "almost science fiction" world of nanomedicine, maybe you too can conceive the next great development. Perhaps in the future tiny nanobots will be able to fulfil custom biological roles such as boosting the production of a particular hormone, burning fat cells, or destroying cancer cells. Tiny materials do great things for human health and will do much more.

**References**

1. . A.L. Porter and J. Youtie, *J. Nanoparticle Res.,* 2009, **11**(5), 1023. [↑](#endnote-ref-2)
2. . S. Bayda, M. Adeel, T. Tuccinardi, M. Cordani and F. Rizzolio, *Molecules*, 2020, **25**(1), 112. [↑](#endnote-ref-3)
3. . M.C. Roco, *Nat. Biotechnol*., 2003, **21**(1), 1247. [↑](#endnote-ref-4)
4. . H. Yolcu and M.A. Dyehouse, *Int. J. Progres. Altern. Educ*., 2018, **14**(4), 37. [↑](#endnote-ref-5)
5. . R. Blonder and S. Sakhnini, *Chem. Educ. Res. Pract*., 2012, **13**, 500. [↑](#endnote-ref-6)
6. . Jones et al., 2013 [↑](#endnote-ref-7)
7. . Dinur and Blonder, 2011 [↑](#endnote-ref-8)
8. . Ulster 2009 [↑](#endnote-ref-9)
9. . Gilbert, 2006 [↑](#endnote-ref-10)
10. . A. Greenberg, *ACS Nano*, 2009, **3**(4), 762. [↑](#endnote-ref-11)
11. . V. Sebastian and M. Gimenez, *Procedia Soc. Behav. Sci*., 2016, **228**, 489. [↑](#endnote-ref-12)
12. . K. Kousha, M. Thelwall and M. Abdoli, *J. Assoc. Inf. Sci. Technol.*, 2012, **63**(9), 1710. [↑](#endnote-ref-13)
13. . M. Pasquali, *EMBO Rep*., 2007, **8**(8), 712. [↑](#endnote-ref-14)
14. . J.E. Hutchison, *ACS Nano*, 2008, **2**(3), 395. [↑](#endnote-ref-15)
15. . A.L. Ramirez-Nuñez, L.F. Jimenez-Garcia, G.F. Goya, G.B. Sanz and J. Santoyo-Salazar, *Nanotechnology*, 2018, **29**(07), 4001. [↑](#endnote-ref-16)
16. . National Research Council (US) Committee for the Review of the National Nanotechnology Initiative, Small Wonders, Endless Frontiers, National Academies Press, Washington D.C., USA, 2002, 36-45. [↑](#endnote-ref-17)
17. . M. Patil, D.S. Mehta and S. Guvva, *J. Indian Soc. Periodontol*., 2008, **12**(2), 34. [↑](#endnote-ref-18)
18. . R.E. Smalley, *MRS Bulletin*, 2005, **30**, 412. [↑](#endnote-ref-19)
19. . J.K. Patra, G. Das, L.F. Fraceto, E.V.R. Campos, M. del Pilar Rodriguez-Torres, L.S. Acosta-Torres, L.A. Diaz-Torres, R. Grillo, M.K. Swamy, S. Sharma and S. Habtemariam, *J. Nanobiotechnology*, 2018, **16**, 71. [↑](#endnote-ref-20)
20. . A.S. Perera and M.O. Coppens, *Philos. Trans. R. Soc. A*, 2019, **377**(2138), 20180268. [↑](#endnote-ref-21)
21. . Y. Deng, X. Zhang, H. Shen, Q. He, Z. Wu, W. Liao and M. Yuan, *Front. Bioeng. Biotechnol.*, 2020, **7**, 489. [↑](#endnote-ref-22)
22. . R. Abu-Much, S. Basheer, A. Basheer and M. Hugerat, *J. Chem. Educ*., 2013, **90**(9), 1207. [↑](#endnote-ref-23)
23. . T.M. Allen and P.R. Cullis. *Adv. Drug Deliv. Rev*., 2013, **65**, 36. [↑](#endnote-ref-24)
24. . G. Bozzuto and A. Molinari*, Int. J. Nanomed*., 2015, **10**, 975. [↑](#endnote-ref-25)
25. . F. Chen, Q. Zhao, X. Cai, L. Lv, W. Lin, X. Yu, C. Li, Y. Li, M. Xiong and X.G. Wang*, Can. J. Microbiol.*, 2009, **55**(11), 1328. [↑](#endnote-ref-26)
26. . R. Petrucci, H. William, F Herring, *General Chemistry: Principles and Modern Applications*, Pearson College Division, New Jersey, U.S.A., 2006. [↑](#endnote-ref-27)
27. . L. Falzone, S. Salomone and M. Libra, *Pharmacology*, 2018, **9**, 1300. [↑](#endnote-ref-28)
28. . M. Christopher, M.S. Hartshorn, G.M. Bradbury, A.E. Lanza, J.R. Nel, Z.W. Andrew, B.W. Ulrich, Y. Lily and P. Grodzinski, *ACS Nano.*, 2018, **12**(1), 24. [↑](#endnote-ref-29)
29. . J.W. Nichols and Y.H. Bae, *Nano Today,* 2012, **7**(6), 606. [↑](#endnote-ref-30)
30. . T.J. Anchordoquy, Y. Barenholz, D. Boraschi, M. Chorny, P. Decuzzi, M.A. Dobrovolskaia, Z.S. Farhangrazi, D. Farrell, A. Gabizon, H. Ghandehari, B. Godin, N.M. La-Beck, J. Ljubimova, S.M. Moghimi, L. Pagliaro, J.H. Park, D. Peer, E. Ruoslahti, N.J. Serkova and D. Simberg, *ACS Nano.,* 2017, **11**(1), 12. [↑](#endnote-ref-31)
31. . G.V. Vimbela, S.M. Ngo, C. Fraze, L. Yang and D.A. Stout, *Int. J. Nanomedicine*, 2017, **12**, 3941. [↑](#endnote-ref-32)
32. . A. Gedanken, *Ultrason. Sonochem.*, 2007, **14**(4), 418. [↑](#endnote-ref-33)
33. . A. Mier, S. Nestora, P.X.M. Rangel, Y. Rossez, K. Haupt and B. Tse Sum Bui, *ACS Appl. Bio. Mater.*, 2019, **2**(8), 3439. [↑](#endnote-ref-34)
34. . P.J. Rivero1, A. Urrutia, J. Goicoechea and F.J. Arregui, *Nanoscale Res. Lett*., 2015, **10**(501), 1. [↑](#endnote-ref-35)
35. . H. Saleem and S.J. Zaidi, *Materials*, 2020, **13**(5134), 1. [↑](#endnote-ref-36)
36. . G. Borkow, *Adv. Mil. Technol.*, 2013, **8**(2), 101. [↑](#endnote-ref-37)
37. . J.M. Benyus, *Biomimicry: Innovation Inspired by Nature*, Perennial, New York, 2002. [↑](#endnote-ref-38)
38. . M. Sarikaya, C. Tamerler, A.K. Jen, K. Schulten and F. Baneyx, *Nat. Mater.*, 2003, **2**(9), 577. [↑](#endnote-ref-39)
39. . J.J. Kim, Y. Lee, H.G. Kim, K.J. Choi, H.S. Kweon, S. Park and K.H. Jeong, *Proc. Natl. Acad. Sci. U.S.A*., 2012, **109**(46), 18674. [↑](#endnote-ref-40)
40. . H. Dodiuk, S. Kenig and A. Dotan, *J. Adhes. Sci. Technol*., 2012, **26**, 701. [↑](#endnote-ref-41)
41. . Y.T. Cheng, D.E. Rodak, C.A. Wong and C. A. Hayden, *Nanotechnology*, 2006, **17**, 1359. [↑](#endnote-ref-42)
42. . P. Morganti, in *Nanocosmetics: Fundamentals, Applications and Toxicity*, eds. A. Nanda, S. Nanda, T.A. Nguyen, S. Rajendran and Y. Slimani, 2020, 1, 3-16. [↑](#endnote-ref-43)
43. . S. Raj, S. Jose S., U.S. Sumod and M. Sabitha, *J. Pharm. Bioallied Sci.*, 2012, **4**, 186. [↑](#endnote-ref-44)