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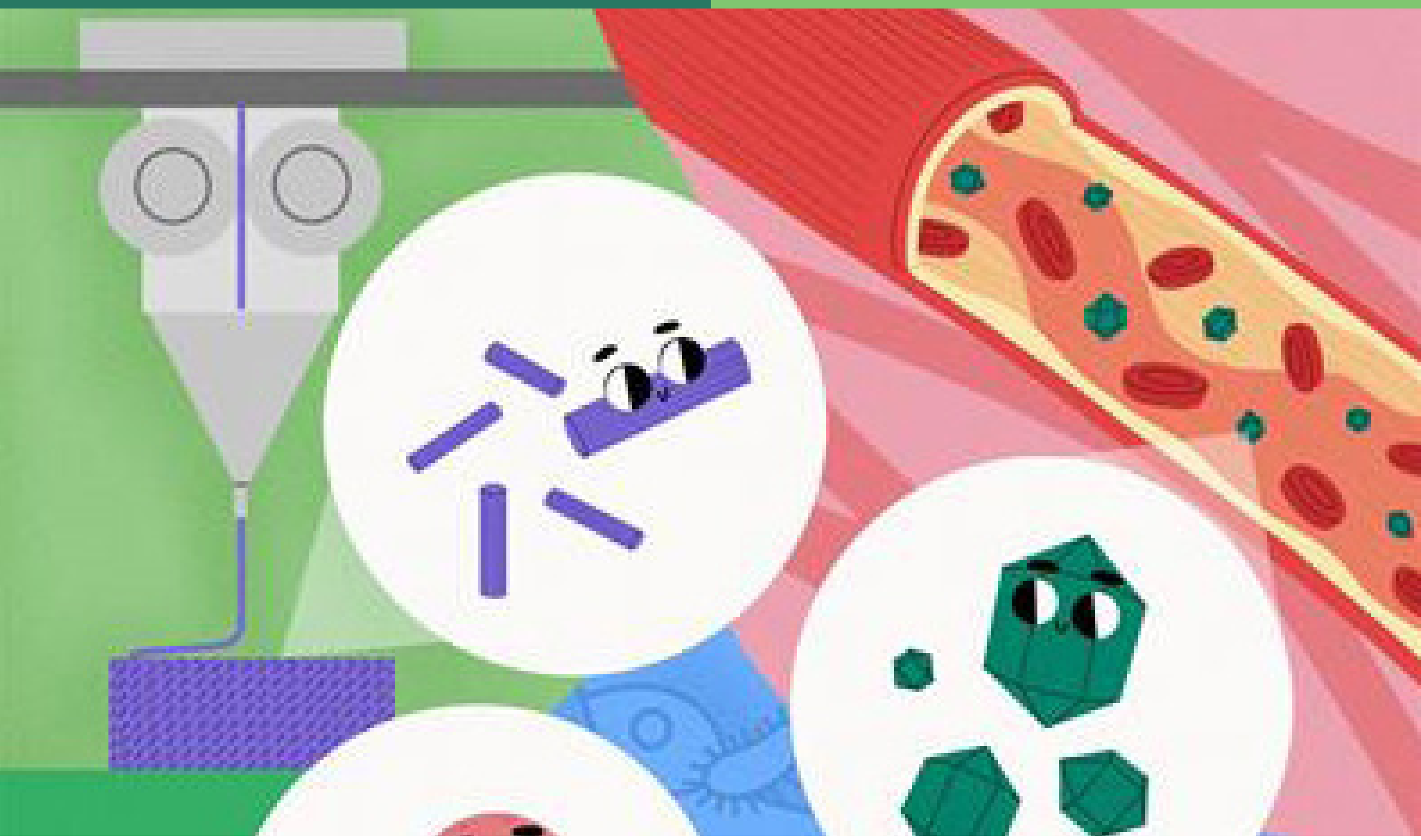
Nanotechnology - The Invisible World

Edited by
Tarryn Lee Botha, Muthumuni Managa and Edward Nxumalo



UNIVERSITY OF JOHANNESBURG

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ISSN 2296-6846
ISBN 978-2-8325-6180-5
DOI 10.3389/978-2-8325-6180-5

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Nanotechnology - The Invisible World

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Citation
Botha, T. L., Managa, M., Nxumalo, E., eds. (2025). *Nanotechnology - The Invisible World.* Lausanne: Frontiers Media SA. doi: 10.3389/978-2-8325-6180-5

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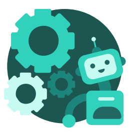


Engineering and Technology

About this collection

This Collection will focus on all aspects of nanotechnology. Did you, for example, know that the nanoscale ranges between 1–100 nm, which is a million times smaller than an average ant! In this Collection, we will provide a brief history of nanotechnology, including what it is and what nanomaterials look like. Articles will illustrate ways that nanotechnology can be used to improve human lives.

When manufacturing nanomaterials, we can change many of their properties also known as their characteristics. Nanomaterials can exist in various shapes, such as spheres, rods, stars, or even tubes. By changing the shape, composition, or size of a nanomaterial, we can change its functions. One famous example, the buckyball, is a carbon-based nanomaterial that looks like a cage; it can be used as a lubricant, or medicines can be loaded within it. Whenever we choose to use nanomaterials, we must first ensure that they are safe for all living things and the environment.

The development of nanotechnology holds great promise for future technological developments. As a fast-developing field, the products of nanotechnology can be found in all aspects of our lives, including food, cosmetics, electronics, and paint. In this Collection, we will explain how nanotechnology can be used to remove pollutants from our water or to develop energy-storage systems, describe how biosensors work, and discuss the challenges faced in ensuring the safe use of nanomaterials.

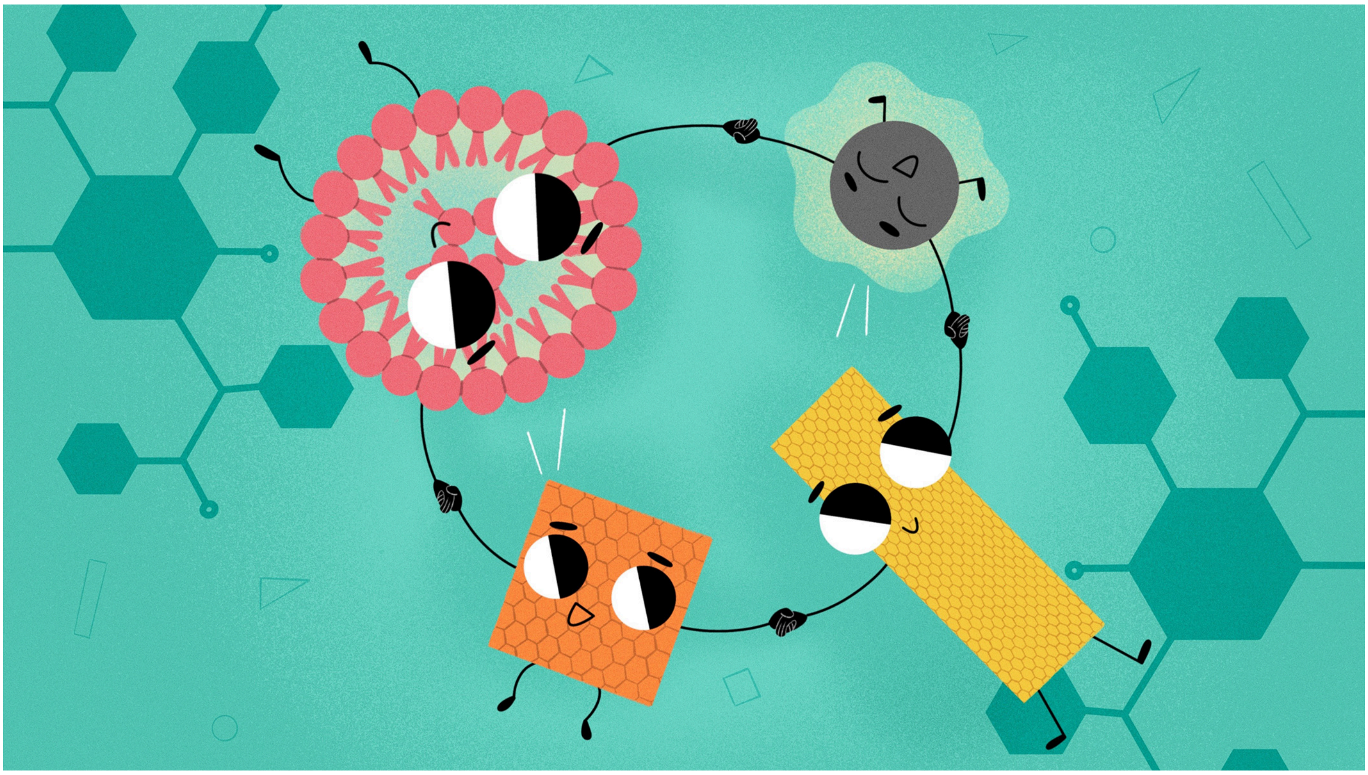
Table of contents

Introduction to the Invisible World of Nanotechnology

Tiny Tech Meets Living Things

Nano Inventions That Make Life Better

ENGINEERING AND TECHNOLOGY
Published: 29 August 2024
doi: 10.3389/frym.2024.1356284



SIZES, SHAPES, AND TYPES OF NANOMATERIALS

Nichole Donough [1*]**,** ***Victor Wepener*** [1] **and** ***Tarryn Lee Botha*** [1,2]

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YOUNG REVIEWERS:

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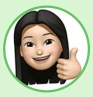
AGE: 10



STEPHANIE
AGE: 13

Nanomaterials are tiny particles, made by breaking down bulk products or by grouping atoms, to form small things, called nanoparticles. Nanoparticles have a size of 1–100 nm, so a person can only see them with a powerful microscope, as they are smaller than the width of a single hair! Nanoparticles are the building blocks of nanotechnology, which is a science used to make many things in our daily lives, like our electronic gadgets, farming chemicals, and medicines. Nanomaterials can come in various shapes, like balls, wires, and rods. They can be flat or have many dimensions. Scientists can produce nanomaterials from carbon, metal, or plastic, giving the nanomaterial special powers, like conducting electricity, absorbing light, or even changing color. These unique powers make each type of nanomaterial useful for a different kind of job. The size, shape, and type of nanomaterial can be seen using many different laboratory methods.

TINY BUT MIGHTY

NANOMATERIALS

Very small particles too tiny to see that are used to make everyday items.

Nanomaterials have been around for a really long time—they are even older than your great-great grandparents! They were first used in the 4th century, which is about 1,700 years ago. The very first nanomaterial was a glass cup that could change colors depending on the light. This cup had tiny particles of silver, gold, and copper inside [1]. Today, nanomaterials are still used in many things, so it is good to understand what they are and how they are made.

NANOPARTICLES

Tiny molecules that are building blocks for nanomaterials.

Nanomaterials are tiny particles that have layers like onions: a core, a surface layer and a shell layer (Figure 1A). They are really small, with sizes ranging from 1 to 100 nanometers (nm, 1 nm is one-billionth of a meter). Nanomaterials can be made in two ways: by breaking down bigger items into tiny pieces or by bringing together really small pieces, such as atoms, to form **nanoparticles** (Figure 1B). These two ways of making nanomaterials can happen naturally, like during volcanic eruptions or forest fires, or because of human activities, like driving cars or using fuel [2].

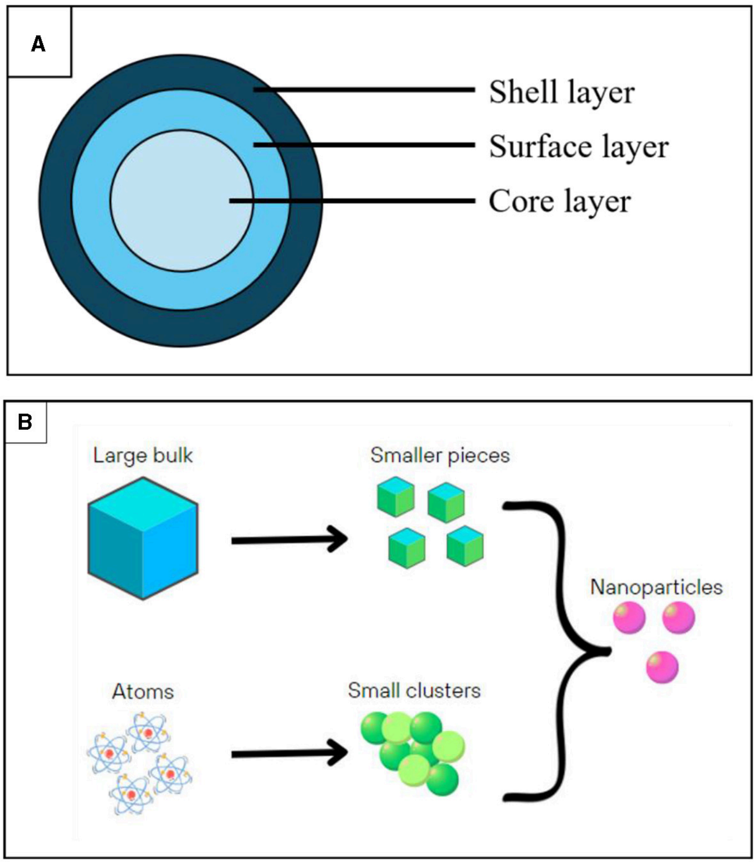


Figure 1

Figure 1

(A) Different layers of nanomaterials. Nanomaterials have a core, followed by a surface layer then a shell layer on the outside. **(B)** Nanomaterials can be made in two ways. A large piece of material can be broken down into smaller pieces (top) or tiny components, like atoms, can be joined together to form small clusters (bottom).

NANOTECHNOLOGY

A science using nanoparticles to create many new things that can help us.

Nanomaterials are like tiny building blocks that are used in the field of **nanotechnology**... almost like the nanobots in the movie *Big Hero*

6! They are found in things that are used every day, such as fertilizers for farming, medical equipment, medicines, and even electronics like cellphones [3]. The nanomaterials used in farming help make sure that the fertilizers do not break down too quickly. The ones used in medicines are super sensitive to conditions in the human body, helping the medicines to get to exactly where they need to go in our bodies.

TRANSMISSION ELECTRON MICROSCOPY

A special type of super-powerful microscope used to view tiny structures.

DYNAMIC LIGHT SCATTERING

A tool that uses light to help scientists learn how big molecules are.

Did you know that nanomaterials are super tiny that they are 10,000 times smaller than the diameter of a single strand of your hair? They are so small that that we may not be able to see them with just our eyes, so we would need special tools to see them. The two very unique tools that scientists use to see these tiny nanomaterials close up: **transmission electron microscopy** (TEM) and **dynamic light scattering** (DLS). The TEM helps us to see the sizes of individual nanoparticles, while DLS shows us how big or small nanoparticles are when they stick together to form clusters in numbers [4]. The DLS can also tell us if nanomaterials have a positive or negative charge on their outer layer. This charge is important because it can affect their clustering, and it can tell us if nanomaterials like or dislike attaching to cells or organisms [5].

Nanomaterials have different sizes and shapes, which can be seen with TEM. We can see that nano-copper oxide nanoparticles (Figure 2A) are bigger than nanodiamonds (Figure 2B). The biggest nano-copper oxide particle is 31 nm, while the biggest nanodiamonds are 7 nm. This means that nano-copper oxide is almost four times bigger than nanodiamonds!

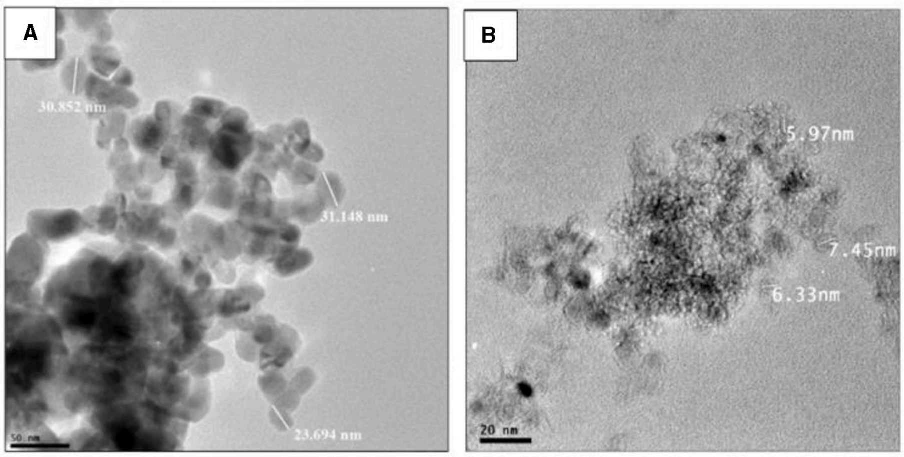


Figure 2

Figure 2

Transmission electron microscopy images of **(A)** nano-copper oxide and **(B)** nanodiamonds. From the sizes in the image, you can see that nanodiamonds are almost four times smaller than nano-copper oxide.

Nanomaterials come in many shapes and dimensions as well. There are four different kinds of dimensions: 0-D, 1-D, 2-D, and 3-D (where D stands for dimensions) [3]. An example of 0-D would be a tiny dot, like quantum dot nanomaterials (they can be fluorescent, almost like they can glow!); 1-D would be a straight line, like nanorods; 2-D would be a square/rectangle, like nanosheets; and 3-D would be two or more structures that are joined together (Figure 3).

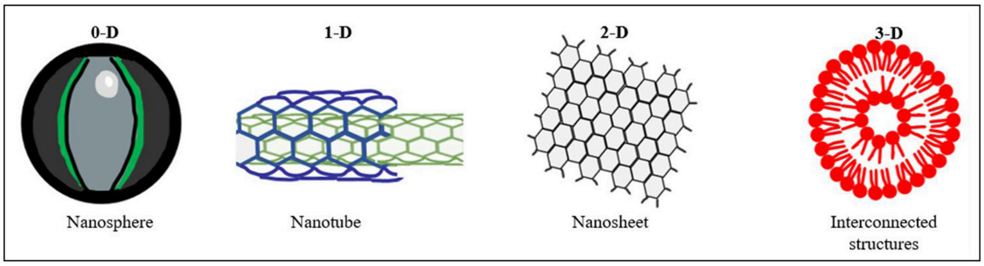


Figure 3

Figure 3

Nanomaterials come in different shapes and dimensions—from dots to tubes to sheets to multiple structures joined together.

Other shapes of nanomaterials include stars, cubes, and cylinders [2]. Nanosheets are found in hair coloring; nanotubes and nanospheres are found in makeup and lotion [6]; and nanodiamonds are used in medical equipment.

WHAT TYPES OF STUFF ARE NANOMATERIALS MADE FROM?

The shapes and sizes of nanomaterials give rise to unique properties, which include the ability to conduct electricity, trap light, if it is strong or weak, and its magnetic strength [2]. Now you know that nanomaterials can come in all shapes and sizes, but what are they made of?

Nanomaterials can be made from four different types of materials: carbon, organic substances, inorganic substances, or composites [3].

Carbon

Carbon is a chemical element that is found in all living organisms. Two different kinds of carbon nanomaterials are graphene [3] and nanodiamonds. Graphene is found in the lead of pencils, which is what we use to write/draw with every day! Nanodiamonds have a special shape called tetrahedral, which means they look like tiny pyramids. They are very strong, which is why nanodiamonds are often used in hospital equipment that helps doctors to see inside our bodies.

Organic substances

Organic substances are substances that have carbon atoms, typically bonded to hydrogen atoms, and may also contain other elements such as oxygen, nitrogen, sulfur, and others. This is a broad category of substances that includes everything from simple molecules like the gas methane (CH_4) to complex structures, like proteins and DNA. Organic nanomaterials include lipids and micelles [3, 7], which can be found in delicious treats like creams, chocolates, and cakes.

ORGANIC SUBSTANCES

Materials from living things, such as plants or animals.

INORGANIC SUBSTANCES

Materials made from non-living things, such as metal or air.

Inorganic substances

Inorganic substances do not have carbon atoms. Metals, metal oxides, and semiconductors can be used for many different purposes [3]. Metals are only made up of one kind of material/element, like copper or zinc. Metal oxides, which are metals attached to oxygen molecules, include copper oxide and zinc oxide. These nanomaterials can have different dimensions, either 0-D, 1-D, 2-D, or 3-D. Finally, semiconductors are interesting as they can have a super strong magnetic force, no magnetic force, or a little bit of a magnetic force. Semiconductors are often used in electronic devices [3].

COMPOSITES

Materials made from two or more particles.

Composites

Composites are combinations of different kinds of nanoparticles [3]. Some composite nanomaterials are made of metal, some are made of ceramic, and others can be made of a special kind of plastic called polymers. They can be found in vacuum cleaners and phone covers, for example.

SUPERHERO OR SUPERVILLAIN?

Nanomaterials are used in things that we use every day, and they often help these things to work even better. But even though they help us sometimes, in other cases nanoparticles can cause problems for other organisms.

Shrimp are water-living animals with a hard covering on their bodies, known as an exoskeleton, that they can remove when it gets too small for them. They can live in freshwater or saltwater and are important in the environment's food webs. We wanted to find out how nanomaterials, like nano-copper oxide and nanodiamonds, affect the shrimp that live in freshwater rivers. Our study found that these nanomaterials made the shrimp breathe more rapidly and act differently than they usually do. This means that the shrimp were stressed out. So, when these nanomaterials are released into the water by humans, they can harm other living organisms, such as shrimp and fish, living in the waters.

Nanomaterials are used to make our lives better, but when they are disposed of incorrectly, they can have bad effects on animals living on land or in the water. So, although they are beneficial for us, we need to be extra careful with them. The use of nanomaterials needs to be "perfectly balanced, as all things should be"—*Thanos: Avengers Infinity War.*

ACKNOWLEDGMENTS

The financial assistance provided from the National Research Fund of South Africa is hereby acknowledged. The work/study is based on the research supported wholly by the National Research Foundation of South Africa (Grant UID: 131599). We acknowledge that any opinions, findings and conclusions or recommendations expressed in this article generated by the NRF supported research, are those of the authors and are not necessarily attributed to the NRF. The NRF accepts no liability whatsoever in this regard.

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SUBMITTED: 15 December 2023; **ACCEPTED:** 13 August 2024;
PUBLISHED ONLINE: 29 August 2024.

EDITOR: Suanne Bosch-Moolman, Cobalt Institute (CI), United Kingdom

SCIENCE MENTORS: Jing Li and Jasleen Kaur

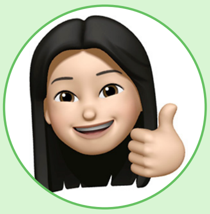
CITATION: Donough N, Wepener V and Botha TL (2024) Sizes, Shapes, and Types of Nanomaterials. Front. Young Minds 12:1356284. doi: 10.3389/frym.2024.1356284

CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

HARKIRAT, AGE: 10

Hi, I am a 4th grader who loves to dream, doodle, and solve puzzles! I really like unicorns, I am super good at hopscotch, and I can solve Rubik's cubes super-fast! One day, I want to try all the cookies and find the yummiest one. When I am not in school, I am either reading cool books, building awesome stuff with my Legos, or challenging myself with tricky puzzles.



STEPHANIE, AGE: 13

My name is Stephanie and I am 13 years old. I am a seventh grader in middle school and my hobbies include singing, playing tennis, and playing the clarinet. My favorite subject in school is ELA and I enjoy reading and writing mystery and dystopian stories. I have performed for the UniverSoul Circus before and I have been a reviewer for some scientific articles in this journal.

AUTHORS

NICHOLE DONOUGH

Nichole's journey as a researcher began with a deep sense of curiosity and passion for issues relating to water systems and how to fix them. She became really fascinated learning about ecotoxicology, especially metal and nanomaterial contamination. Through her studies, she learned that organisms can be used as indicators in helping us assess the health of a water system and understanding the impact it has on aquatic life. Learning about pollutants in aquatic ecosystems is very important, not only because of the harm it as on animals living in those systems, but also due to the potential harm it can inflict on our health. Nichole's research in ecotoxicology continues to ignite her curiosity where every day is an opportunity to learn something new and to share what she learns with others.*nicholedon@gmail.com

VICTOR WEPENER

Victor Wepener is a Professor of Zoology at North-West University, South Africa. He co-leads a group known as the Water Research Group, and he has written multiple papers, books, and reports on how chemicals, like nanomaterials, affect our water systems and the animals within it. Wepener has taught many young scientists about aquatic systems and their pollutants, and he is the chairperson of a large group known as the South African Department of Science and Innovations Environment, Health and Safety Nano Risk Assessment research platform. He also represents the South African Bureau of Standards at the ISO nanotechnologies

TC229. This means that he works with important organizations to help ensure that new technologies are safe. Wepener is the head of a laboratory known as the National Aquatic Bioassay Facility (funded through the National Nanotechnology Equipment Programme), which is a high-tech laboratory to do experiments in, like studying water contamination and the effects it has on aquatic organisms.

TARRYN LEE BOTHA
Having clean water is a human right, and as aquatic scientists it is part of our job to ensure that safe, clean water is available to everyone. Contaminated water can be cleaned using nanotechnology in water purification, but just like with any new technology, it needs to be tested to ensure it is safe to use. Many organisms, like earthworms, fish and crustaceans like daphnia, are used to test waters for nanomaterial contamination and we have even conducted some of these tests in a state-of-the-art laboratory. An important concept is an Adverse Outcome Pathway Approach, and this includes looking at responses of an organism, such as their growth, respiration, heart rate and behavior, to ensure that all the right points are monitored. This approach is like following a roadmap to make sure nothing important is missed, and we can use this roadmap data to tell us how it might affect human health.

ENGINEERING AND TECHNOLOGY
Published: 28 February 2025
doi: 10.3389/frym.2025.1414735

WHAT ARE NANO-BASED PRODUCTS AND WHO USES THEM?

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YOUNG REVIEWERS:

LEON
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NIKHIL
AGE: 13

Nanotechnology is a game-changer in many modern industries. Nanotechnology uses super-small particles with special characteristics to make many types of products. Nano-based products are making big waves in the medical, clothing, and electronics industries, to name a few. For example, nanomaterials can help to clean water and fight pollution. In medicine, nanotechnology is super useful for precise treatments, like delivering drugs straight to where they are needed in the body. In electronics, nanotechnology can help to make devices smaller and better. Even clothes are getting an upgrade with nanotechnology, making them "smart" and resistant to stains or germs. Overall, nanotechnology is driving innovation by making materials better, devices faster, and medical treatments more effective. This technology is shaping a future full of tiny yet powerful changes.

TINY PARTICLES WITH A BIG IMPACT

NANOPARTICLES

Tiny particles that range between 1–100 nanometers (nm) in diameter.

NANOTECHNOLOGY

A field of science involving materials at the molecular scale smaller than 100 nm.

Nanoparticles, both natural and manmade, are tiny structures that range between 1 and 100 nanometers (nm) in diameter. **Nanotechnology** might seem new, but did you know that it was developed way back in 1856, when a famous scientist named Michael Faraday produced nanoparticles made of gold? Today, more than 150 years later, nanotechnology is changing how many industries function, and it is producing new products we use in our daily lives. Nanoparticles are microscopic—you cannot see them with the naked eye—and this allows them to have super-cool qualities. Structures made from nanoparticles make products stronger, lighter, more durable, and better at conducting electricity, to list just a few useful qualities. Scientists are actively studying nanomaterials, trying to figure out all the many ways we can use them to improve our lives (Figure 1).

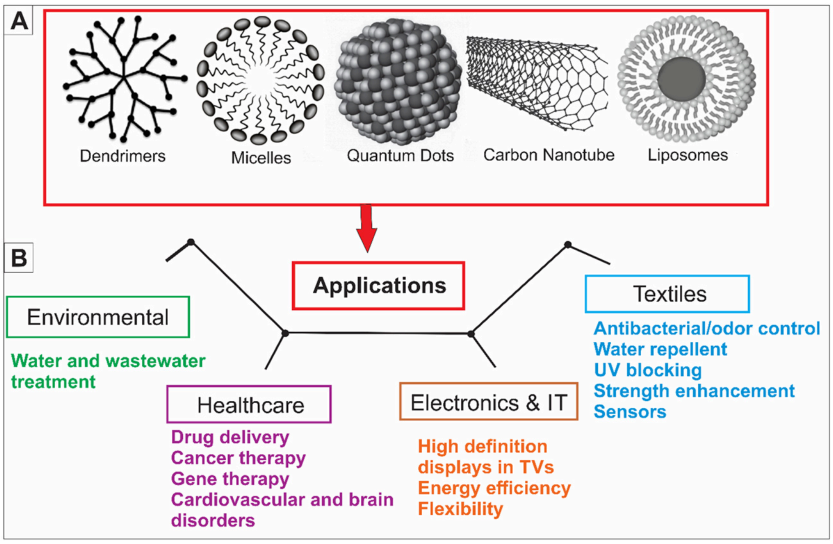

Figure 1

Figure 1

(A) Nanoparticles can have various shapes at the microscopic level. **(B)** Nanoparticles can be used in numerous applications in modern life.

ENVIRONMENTAL USES

We can use nanoparticles to help our environment and save our ecosystems. We all understand how important freshwater resources are, and we know that they are being polluted by chemicals, sewage, oil spills, and plastic. But did you know that nanotechnology can help clean up this pollution? For example, scientists have created magnetic, water-repellent nanoparticles that can remove oil from water after oil spills [1]. This not only cleans water sources during these accidents but also saves many fish and bird species that live in and use the water. Nanoparticles can also be used in chemical reactions that change harmful chemicals that pollute groundwater into harmless substances (Figure 2A) [2]. Some filters, like the ones in airplane cabins, have tiny, nano-sized pores—these filters are used to purify the air, so that passengers can travel safely. Because their design and the pores in the filters are so small, they can trap even the tiniest germs and other pollutants, reducing the risk of transporting harmful substances and germs from one place to another [3].

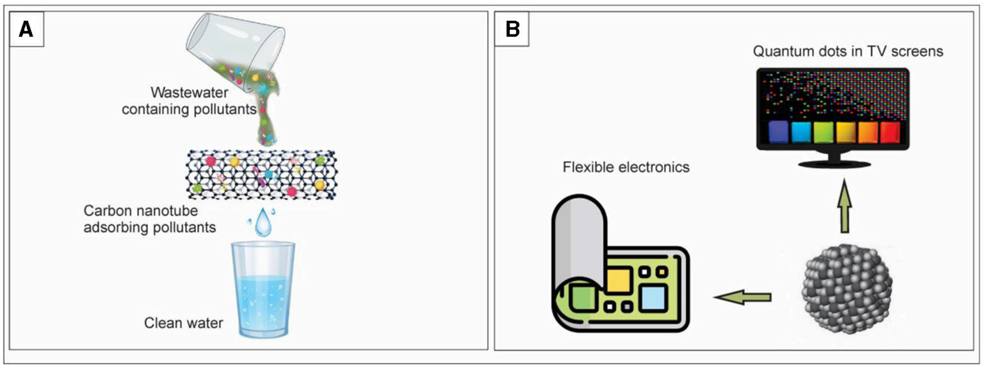

Figure 2

Figure 2

(A) Nanotubes made of carbon can be used to help protect the environment by treating polluted wastewater. **(B)** Uses of nanomaterials in electronics include quantum dots in TV screens and flexible electronics.

ELECTRONIC AND INFORMATION TECHNOLOGY USES

Nanotechnology also plays a key role in our daily lives through the ever-developing world of electronics and information technology (IT). Electronic parts are becoming smaller and smaller and gaining enhanced abilities thanks to nanomaterials. Nano-sized parts are already part of our daily lives, but often we do not even know they are there. For example, new ultra-high-definition television screens use **quantum dots** to produce more vibrant colors, thereby increasing the quality and improving the watcher's experience when viewing their favorite movie (Figure 2B) [4]. The tiny dots also reduce the amount of energy a television uses, protecting the environment and reducing our electricity bills. Nanotechnology can also be found in our smartphones, thumb drives, keyboards, and even in hearing aids—products that many depend on in the modern world [5]. Do you know that scientists have even produced flexible electronics with nanotechnology? These include wearable sensors and electronics like flexible solar panels or devices that can be sewn into clothing, and even electronic paper that can be folded and rolled up. These are just a few examples of how nanotechnology can improve electronics and IT applications.

QUANTUM DOTS

Extremely tiny particles that glow in different colors when light shines on them. Scientists use them to make bright reds, greens, and blues in screens and other technologies.

HEALTHCARE AND MEDICAL USES

Nanotechnology also improves our lives through healthcare and medical applications (Figure 3A). Nanomaterials inside medicine-containing capsules can help the medicine to be more effective, by getting it exactly where it is needed after it is swallowed. Nanomaterials can also be used in nose sprays that are inhaled. Scientists have even used "clever" nanoparticles to deliver

CHEMOTHERAPY

A type of cancer treatment that uses chemical substances to destroy abnormal cells.

Figure 3

(A) Applications of nanoparticles in the medical industry. **(B)** Uses of nanomaterials in fabrics in the textile industry.

GRAPHENE

A form of carbon consisting of sheets with the atoms arranged in a honeycomb shape.

chemotherapy medication directly to cancer cells, minimizing the damage to healthy tissues nearby and thereby greatly improving cancer treatments. This breakthrough could reshape cancer treatment approaches, significantly reducing the toxic effects of chemotherapy on healthy cells and potentially saving lives in the future.

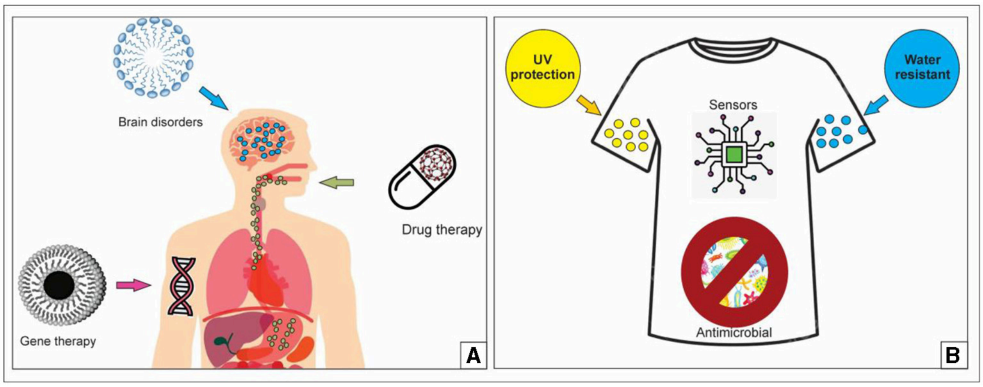

Figure 3

Scientists have also produced nanoribbons made from **graphene**, and early studies show that nerve cells can thrive on these graphene surfaces. In the future, such technologies might be used to help repair spinal cord injuries in paralyzed patients [6]. Such innovative uses highlight the impact of nanotechnology in modernizing healthcare and medical research [7]. Scientists all over the world are recognizing nanotechnologies and nanoscience as important fields. In 2023, the Nobel Prize in Chemistry was awarded to Moungi Bawendi, Louis Brus, and Alexei Ekimov for their discoveries and contributions in the field of nanotechnology.

TEXTILE AND CLOTHING USES

Have you considered that you might be covered in nanomaterials right now? The textile and clothing industry is changing drastically as it begins to use nanomaterials. Incorporation of nanomaterials into clothing could have uses in many fields, including health, pharmaceuticals, fashion, sports, military, and transportation. Some nanofiber-containing clothes are already being sold, and they have incredible properties like resistance to stains or to the sun's dangerous UV rays. Fabrics can also be designed to contain antimicrobial features that kill germs (Figure 3B). This application can already be seen in socks that kill the bacteria that produce the odor from sweaty feet. Nanotechnology can also be used to create fabrics that are resistant to flames. Incredibly, scientists have also produced "smart" textiles that can change color in response to changes in the surrounding environment, such as changing color when the temperature changes; some of these items are already available in speciality shops [8].

In conclusion, although nanotechnology might sound like a futuristic field of study, it is already part of our everyday lives. Nanomaterials help us to protect our environment by cleaning the water and air that we all depend on. They have also led to modern advances in electronics and healthcare practices. Nanomaterials are even changing how we see ourselves, becoming part of the clothes we wear daily. New advances in nanotechnology are happening rapidly, so the examples we described in this article are only a small fraction of the advancements that we are likely to see in the near future!

ACKNOWLEDGMENTS

We would like to acknowledge the University of Johannesburg for equipment and facilities, the National Research Foundation of South Africa (NRF) for a partial doctoral grant to LL and NRF Support for Rated Researchers (Reference: SRUG22052013241-PR-2023) and University of Johannesburg Faulty and Central Research Committees for grants to AA-O.

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SUBMITTED: 09 April 2024; **ACCEPTED:** 07 February 2025;
PUBLISHED ONLINE: 28 February 2025.

EDITOR: Edward Nxumalo, University of South Africa, South Africa

SCIENCE MENTORS: Divya Gopinath and Junhong Chen

CITATION: Latief L, Dahms HTJ and Avenant-Oldewage A (2025) What Are Nano-Based Products and Who Uses Them? Front. Young Minds 13:1414735. doi: 10.3389/frym.2025.1414735

CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

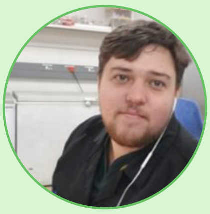
YOUNG REVIEWERS

LEON, AGE: 13
Leon is a curious 13-year-old with a passion for science, especially astronomy, biology, and physics. He loves exploring science fiction, particularly The Remembrance of Earth's Past Trilogy. Leon enjoys trying new foods from around the world, including Thai, Chinese, Italian, and Japanese cuisines.

NIKHIL, AGE: 13
Nikhil is fascinated by the world of science, specifically astrophysics and microbiology. He is a funny kid who loves goofing around and being silly as well as geeking out on black holes and warp drives in equal measures.

AUTHORS

LUTFIYYA LATIEF
Hai, my name is Lutfiyya, I am a PhD student studying tiny particles called nanoparticles in fish and tiny creatures that live on these fish, called parasites. Nanoparticles are so small that we need special tools to see them. I am trying to understand how these nanoparticles affect the fish and the parasites. By learning about this, we can help keep the fish healthy and find new ways to fight parasites that make these fish sick.



HEINRICH THEODOR JACOB DAHMS

My name is Heinrich, and I am a post doc researcher in the Institute of Alpine Environment in Eurac Research. I specialize in microplastics, which are tiny, microscopic pieces of plastic smaller than 5 mm. I am trying to understand how microplastics behave in rivers, to understand how they might impact ecosystems. I have detected microplastics in five rivers across South Africa, including the Vaal and Limpopo Rivers. I have always had a passion for the environment, and I firmly believe that a life where you contribute to a better world is the greatest life you can live.

ANNEMARIÈ AVENANT-OLDEWAGE

I study the effect of environmental substances on parasites of various fish species. Many of the parasites are very sensitive to these substances and their numbers become reduced and eventually they even become locally extinct. This is an early warning to humans that the water may also not be safe for human consumption. I work with a group of postgraduate students and postdoctoral fellows, and we are interested in applying this knowledge in water quality monitoring.

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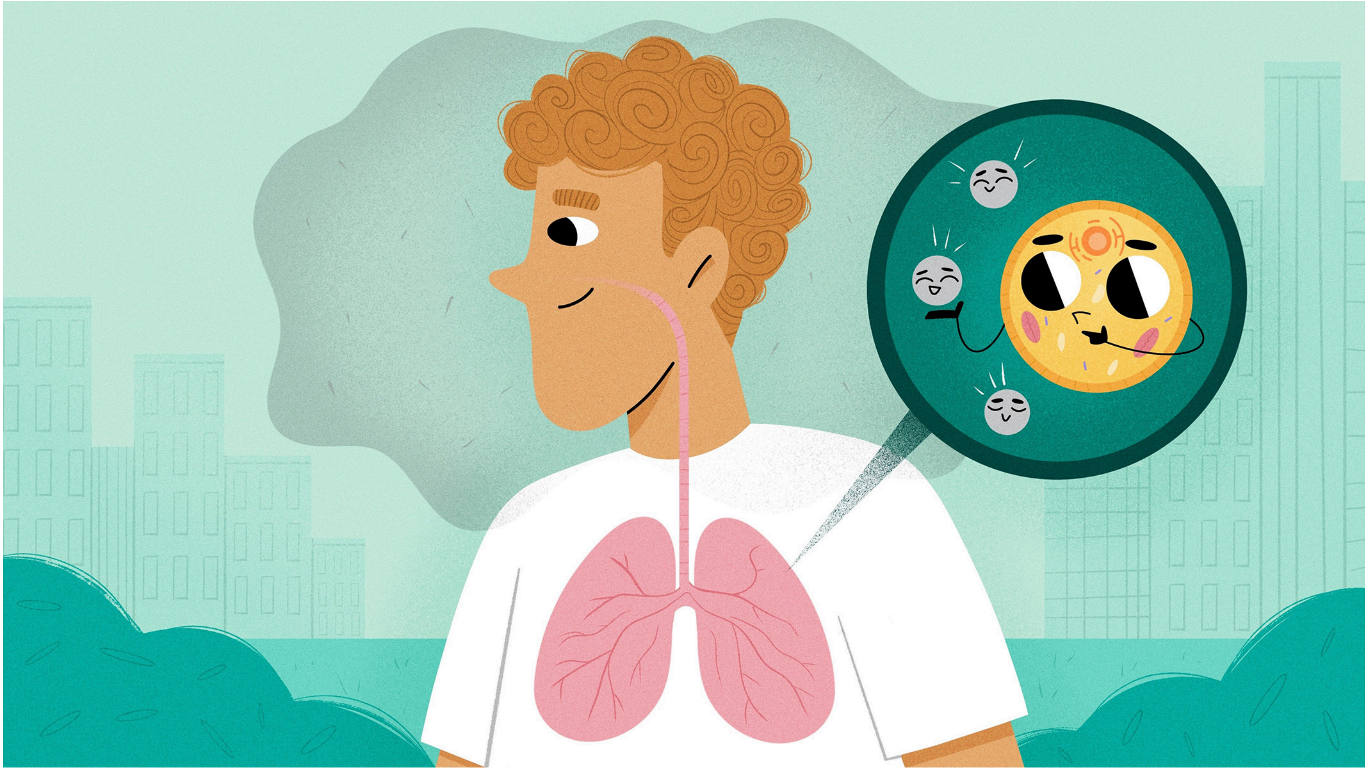
HUMAN HEALTH
Published: 30 August 2024
doi: 10.3389/frym.2024.1356375



IS "SMALL" SAFE? EXPLORING THE GOOD AND BAD OF NANOMATERIALS

Charlene Andraos [1*], ***Kailen Boodhia*** [2] ***and Tarryn Lee Botha*** [3]

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[3] *Department of Zoology, University of Johannesburg, Johannesburg, South Africa*

YOUNG REVIEWERS:

KONSTANTIA
AGE: 10

MIDDLE SCHOOL PARINI-MERELLO
AGES: 12–14

"Small" does not necessarily have a clear meaning... is a ball big or small? A ball might be small compared to the entire planet, but it is absolutely huge compared to tiny "nano" particles! If you look at 1 mm on a ruler, one *million* nanometers can fit into that millimeter. Nanomaterials—the general name for materials made from tiny particles in the nanometer range—are so small that they have properties that can be quite different from "normal" materials. Nanomaterials may have a number of helpful functions. For example, they can be useful in medicine, helping our bodies to fight infections from bacteria and viruses. Nanomaterials can also be included in some products, to make them stronger or longer lasting. However, despite their advantages, we must be cautious with nanomaterials

because they can sometimes get past the barriers in the human body that protect us from foreign invaders, causing damage to cells and potentially making people sick. Let us see how their size changes where they go and what they can do.

THE NANOSCALE

The term "nano" comes from the Greek word "nanos", which means "extremely small". When we say nanoscale, we are referring to a size range of 1 to 100 nanometers (nm)—the ideal range for investigating teeny-tiny particles and materials. To give you an idea of how small this is, consider a single human hair. Even one hair is much larger than anything on the nanoscale! A hair's thickness ranges from 60,000 to 100,000 nm (0.06 to 0.1 mm), and a sheet of paper is ~75,000 nm (0.075 mm) thick. A bacterial cell is 10,000 nm (0.01 mm), a tiny red blood cell is ~7,000 nm (0.007 mm) in diameter, a fungi spore is 500 nm (0.0005 mm) and a virus is just between 20 and 200 nm (0.00002 to 0.0002 mm). Now consider this: the radius of a DNA molecule is only 1 nm!

NANOMATERIALS

These are very tiny materials, so small you cannot even see them with the naked eye.

Nanomaterials, the general name for any material in the nanoscale, can range from 0.7 nm in size, such as graphene and carbon nanotubes, all the way up to 80 nm in the form of nanogold, for example [1]. Does this give you an idea of how small nanomaterials are? Figure 1 shows how big nanomaterials are compared to a dog, its tennis ball, a flea, an animal cell, and a bacterial cell.

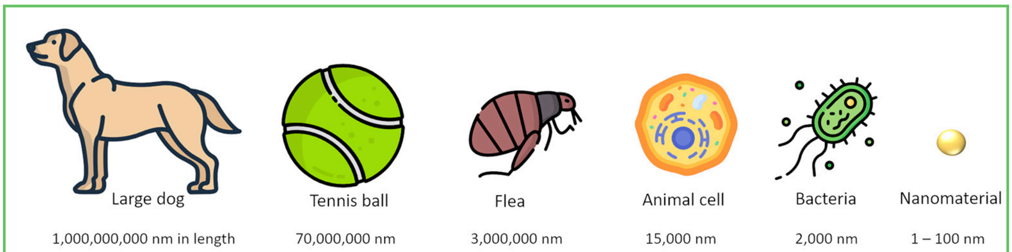

Figure 1

How small is the nanoscale? The sizes of the objects shown give you an idea of just how tiny nanomaterials are.

HOW ARE NANOMATERIALS CHANGING THE WORLD?

Because nanomaterials are so small, they have special properties. Figure 2 shows the use of graphene nanomaterials in bulletproof vests, for example. Traditional bulletproof vests are typically made from very strong plastic. Scientists can strengthen these bulletproof vests by adding graphene sheets to the plastic. This is because the graphene sheets are extremely strong but weighs less than a piece of paper. This nanomaterial can absorb the impact of the bullet, so that the person wearing it does not get hurt.

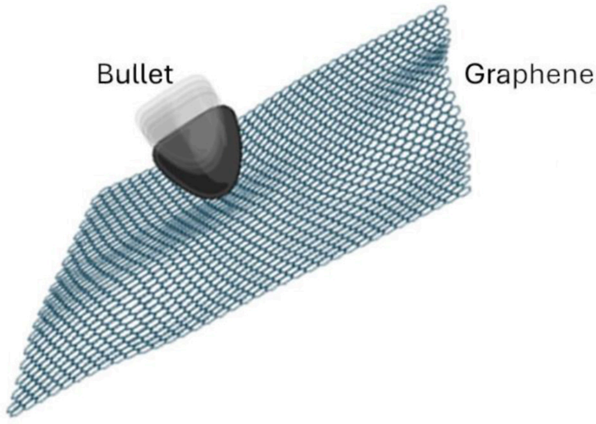

Figure 2

Figure 2

A nanomaterial made of graphene can be used in bulletproof vests. This material can take more impact from a bullet due to its structure.

If you think 3D printing is cool, just wait until 4D printing using nanomaterials as tiny building blocks becomes a reality. Regular 3D printers can build awesome toys but imagine if printers could print toys that transform after printing! That is 4D printing—it uses nanomaterials that change shape under different conditions. Scientists design these nanomaterials to react to heat, light, or water, so they can transform for various uses. Imagine clothes that get warmer when you are cold! 4D printing is new, but it has the potential to do amazing things, especially in medicine. Imagine new bandages that changes color to let you know that your body is not healing properly or can alert you to replace the bandage for a new one. Or imagine tiny robots that help you heal from an injury [2, 3].

Nanomaterials have several other uses in medicine, too. For instance, doctors could treat diseases using nano-sized medicines that can reach sick cells in locations that regular medicines cannot get to. Even certain cancers can be treated with tiny nanodrugs that deliver medicine right to the specific part of the body where it is needed [4].

Nanomaterials can also play an important role in vaccines, especially in some COVID-19 vaccines [5]. These vaccines contain nano-sized bubbles called **liposomes**. Scientists can put pieces of the virus (or even instructions telling your body to make its own defenses) inside these liposomes. The liposomes protect the vaccine parts as they travel into your body, and they help the vaccine to get to the right cells to trigger protection. This can make the vaccine more effective and require fewer doses. So, next time you get a vaccine, especially for COVID-19, there is a good chance tiny nanomaterials are helping keep you healthy! Using powerful microscopes, we can "see" nanomaterials and how they interact directly with human cells (Figure 3A).

LIPOSOMES

Tiny bubble-like structures that are made of fat and that carry medicine inside them.

Nanomaterials can also help clean up pollution in water, making our world a healthier place. Finally, as nanomaterials are becoming more

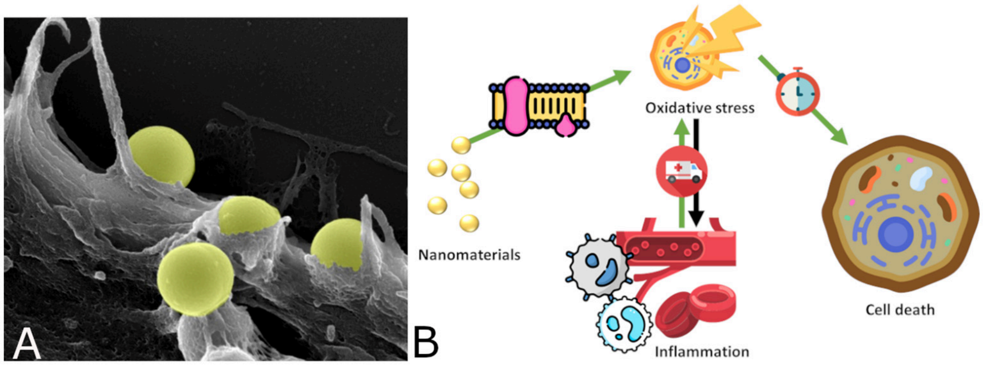

Figure 3

Figure 3

(A) A super-powerful microscope called a scanning electron microscope was used to take a picture of nanobeads made of silica (yellow) on the surface of a human cell (image credit: Matthew Ware and Biana Godin Vilentchouk, Houston Methodist Research Institute, Texas). **(B)** Nanotoxicity can happen when nanomaterials cause uncontrolled inflammation, which leads to a condition called oxidative stress, which can kill cells. Oxidative stress itself can also increase inflammation, making the situation worse (adapted from [6]).

common, they can even be found in some packaged snacks. They are usually part of the packaging, used to make it stronger, or they can even be used as an ingredient of the snack itself, to keep it fresher or even to fight off bacteria [7]. This is an area that is still being researched, so scientists are figuring out the best ways to use nanomaterials safely.

HOW DO NANOMATERIALS ENTER THE HUMAN BODY?

Nanomaterials typically enter the human body in three ways. First, they can enter through the skin. The skin normally functions as a shield, but it cannot prevent the entry of nanomaterials that are found in some sunscreens, for example. Second, if nanomaterials are inhaled, they can enter through the respiratory system [8]. Due to their small size, the body cannot expel them. Currently, scientists are not exactly sure how bad it is for humans to inhale nanomaterials in the long term, but experiments in the laboratory have shown that nanomaterials in the lungs can be very bad—some can even lead to permanent tissue damage. Finally, nanomaterials can enter through the digestive system, when people eat foods containing these materials as additives like colorants or preservatives.

DOES THE HUMAN BODY DEFEND ITSELF AGAINST NANOMATERIALS?

The human body has many defenses against foreign bodies, such as the mucous membranes in the respiratory and digestive tracts, which trap foreign substances, and the acidity (low pH) of the stomach. In an acidic environment, many types of invaders are killed or dissolved. With nanomaterials, this does not always work. In fact, nanomaterials can bind with normal proteins present in the stomach, creating new structures called **biocoronas**. Biocoronas can pass through the body unnoticed, as if wearing an invisibility cloak. Therefore, the body's cells

BIOCORONA

The structure created when molecules from the body, such as proteins, stick to the surface of a non-biological substance, such as nanomaterials, basically disguising them.

specialize in recognizing and killing foreign invaders do not detect the nanomaterials and thus do not attack them.

NANOTOXICITY

This is when nanomaterials can cause harm to living things (people, animals and the environment). Scientists are still learning about this.

INFLAMMATION

The body's reaction to infections and injuries, often appearing as redness and swelling. Too much or long-lasting inflammation can cause cells to die through oxidative stress.

OXIDATIVE STRESS

A process that happens when harmful molecules produced by inflammation damage cells. It can lead to diseases and aging. The body has natural defenses to help protect against it.

WHAT ARE THE NEGATIVE CONSEQUENCES OF NANOMATERIALS IN THE BODY?

The negative effects that nanomaterials can have on the human body are known as **nanotoxicity**. In some cases, cells recognize nanomaterials as dangerous and attempt to eliminate them through **inflammation**. Inflammation may produce toxic by-products which, under normal conditions, do not do much damage. However, if there is lots of inflammation or if it lasts a long time, these toxic by-products can damage the body's cells or even cause them to die through a process called **oxidative stress**. Imagine your body is a playground, and the toxic byproducts of inflammation are like little troublemakers bouncing around. Normally, your body has "playground monitors" called antioxidants that grab these troublemakers before they cause any damage. But if there are too many troublemakers and not enough monitors, things can get out of control! That is kind of like what happens during oxidative stress, which can then lead to even more inflammation, in a vicious cycle (Figure 3B) [3]. Some nanomaterials cannot be removed or destroyed and remain in the body for years. Continuous inflammation may also lead to tumors over time.

CONCLUSION

Nanomaterials offer exciting possibilities, from medical treatments to pollution clean-up. However, their small size presents a double-edged sword. While it gives them special properties, it also allows them to bypass the body's natural defenses, which if out of control can cause inflammation and even cell death. As research into nanomaterials continues, so too must our understanding of their possible risks. By weighing up the potential risk and amazing benefits we can ensure a future where nanotechnology continues to improve our lives without affecting our health.

ACKNOWLEDGMENTS

The financial assistance provided from the National Research Fund of South Africa is hereby acknowledged. The work/study is based on the research supported wholly by the National Research Foundation of South Africa. We acknowledge that any opinions, findings, and conclusions or recommendations expressed in this article generated by the NRF supported research, are those of the authors and are not necessarily attributed to the NRF. The NRF accepts no liability whatsoever in this regard.

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SUBMITTED: 15 December 2023; **ACCEPTED:** 13 August 2024;
PUBLISHED ONLINE: 30 August 2024.

EDITOR: Ornella Cominetti, Nestlé Research Center, Switzerland

SCIENCE MENTORS: Andreas Skiadopoulos and Carmine Tommaso Recchiuto

CITATION: Andraos C, Boodhia K and Botha TL (2024) Is "Small" Safe? Exploring the Good and Bad of Nanomaterials. Front. Young Minds 12:1356375. doi: 10.3389/frym.2024.1356375

CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

KONSTANTIA, AGE: 10

Konstantia is a curious 10-year-old girl who loves reading as much as the next person! Her passion for reading excites her whenever she discovers a good book. Having lived in various places around the globe, she has mastered three languages. Konstantia adores interacting with other kids. If it were up to her, she would play all day long!

MIDDLE SCHOOL PARINI-MERELLO, AGES: 12–14

We are 150 students (12–14 years old) from seven classes (2A, 2B, 2C, 2E, 2F, 2I, 3G) of the Parini-Merello Middle School of Genova. Thanks to our teachers, the school is involved in many projects, and we are lucky to have many exciting experiences! The Frontiers for Young Minds project was one of the best: we thought that it would have been a very challenging job, but once we started working all together, we had so much fun, and our curiosity helped us in carrying out the review work!

AUTHORS

CHARLENE ANDRAOS

My work centers on the development and refinement of testing methodologies in the laboratory, specifically aimed at assessing the mechanisms of toxicity of particles, particularly nanomaterials. In addition, my research delves into the potential health risks associated with nanomaterial exposure. As a toxicologist specializing in airborne particles, I am particularly intrigued by understanding how the unique characteristics of nanomaterials may result in potential human health implications. This work excites me as it requires knowledge from many scientific fields including biology, human anatomy, and chemistry, among others. *charlenea@nioh.ac.za

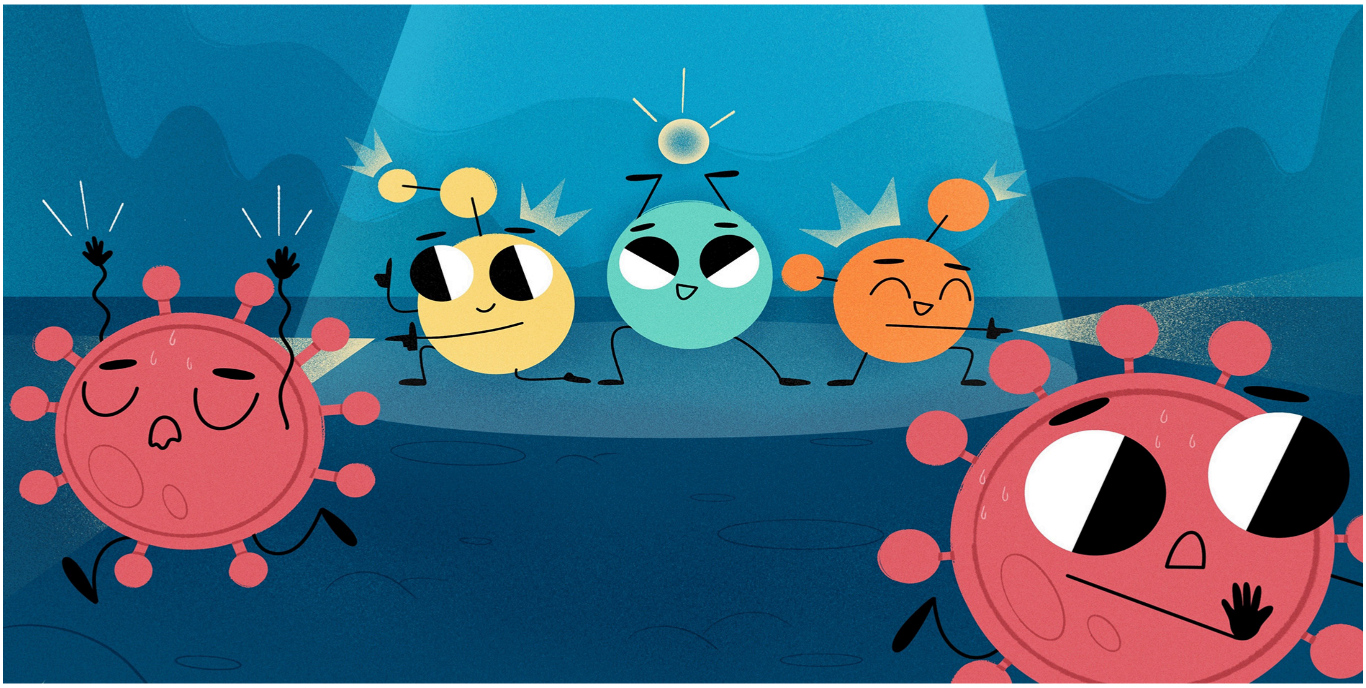
KAILEN BOODHIA

What intrigued me into becoming a scientific researcher? My curiosity about how do things work and the fact that I like working with my hands. I like to understand how testing methodologies work, and then combine or modify them to try something new. Most of my research career has focused on the assessing the toxicity of nanomaterials, considering inhalation as one of the major routes of exposure. I started exposing lung cells in a tissue culture dish, and now I am working on one of the first nano aerosol exposure systems in South Africa.

TARRYN LEE BOTHA

My research is curiosity driven; "we are only limited by our imagination" is a philosophy I live by. I studied zoology and biochemistry, which led me to become an expert in aquatic health. I study how safe water is to drink and whether we can sustain a high level of biodiversity in aquatic systems. Nanotechnology is an emergent field and rather than waiting to see whether it poses a risk, it is better to develop products with potential risks in mind—we call this safety by design. We work in complex teams that involve chemists, biologists, ecotoxicologists, inhalation experts, and policy makers.

HUMAN HEALTH
Published: 16 July 2024
doi: 10.3389/frym.2024.1377991

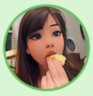


A NEW WAY TO TREAT DISEASES USING LIGHT-LOVING MOLECULES

Muthumuni Managa*[*], *Tracy G. T. Moraba, Nonkululeko Malomane and Kwanele Nene

Institute for Nanotechnology and Water Sustainability (iNanoWS), College of Science, Engineering and Technology, University of South Africa, Florida Campus, Johannesburg, South Africa

YOUNG REVIEWERS:



ARIANA
AGE: 8

KABIR
AGE: 12

Some tiny microorganisms creatures such as viruses, fungi, and bacteria can make us very sick. As these organisms evolve with us, they are becoming smarter and stronger, which is making it more difficult for medicines like antibiotics to fight them. Scientists are finding new ways to treat these infections, and one way is by using a cool treatment called photodynamic antimicrobial chemotherapy (PACT). PACT is based on tiny, colored molecules that take up light and use it to make tiny "bullets". These tiny bullets attack and kill microorganisms by punching holes in their cell membranes. Therefore, using PACT could help doctors and scientists to fight these attacks and keep people healthy.

HARMFUL MICROORGANISMS ARE FIGHTING BACK AGAINST TREATMENTS!

MICROORGANISMS

Tiny living things that exist around us which we cannot see without special tools like microscopes.

Have you ever wondered what makes us sick and how we get diseases? Well, we live in a world where tiny living things called **microorganisms**, which we cannot see without special tools like microscopes, exist all around us. There are two main kinds of microorganisms: harmful microorganisms and beneficial microorganisms. Harmful ones can make us feel sick, while beneficial ones are like little helpers that take part in normal body processes like digesting food, getting rid of toxins, making vitamins, and strengthening our immune systems. Microorganisms include bacteria, viruses, fungi, and protozoa, and they exist all around us.

ANTIBIOTICS

Medicines that fight off bacterial infections in humans and animals by either killing the bacteria or making it hard for it to grow.

ANTIBIOTIC RESISTANCE

A process by which microorganisms become stronger over time and stop responding to antibiotics.

Microorganisms can cause diseases as they spread through the air, water, soil, food, or even when we touch each other like when we shake hands. When it comes to bacteria, there are medicines called **antibiotics** that can fight the bacteria and help us get better. But not all bacteria die when people take antibiotics. Some survive and become stronger against the medicine, which is called **antibiotic resistance** [1]. The next time we use the same medicine, it will not work as well. These strong microorganisms can share their resistance superpowers with other microorganisms, making them resistant, too. Even normal beneficial bacteria can change to become harmful with time in the presence of antibiotics.

PHOTODYNAMIC ANTIMICROBIAL CHEMOTHERAPY

A new tool to fight off diseases using light, dyes, and oxygen.

Another downside of antibiotics is that sometimes they also harm the beneficial bacteria that we need in our bodies, like *Lactobacillus*, which helps with digestion [2]. When beneficial bacteria die, this can make it easier for dangerous bacteria to grow. As we mentioned, if harmful bacteria become resistant to antibiotics, they are much harder to fight. Luckily, scientists are working hard to find new ways to beat harmful bacteria and keep us healthy.

WHAT SOLUTION DO WE HAVE?

Scientists have discovered a cool new way to fight bacteria, called **photodynamic antimicrobial chemotherapy** (PACT). PACT can help us when regular antibiotics can no longer do the job [2]. Research on PACT is currently happening all around the world, and in some countries, like the USA, it is now being tested in humans [3].

LIGHT-LOVING MOLECULE

Any molecule that can take up light energy and convert it into any other form of energy.

REACTIVE OXYGEN SPECIES

Small substances produces by light-loving molecules in the presence of light that target and kill microorganisms.

PACT uses light to fight against harmful microorganisms. You probably know that plants use sunlight to make their food by photosynthesis, right? Well, PACT works similarly. Plants have a natural **light-loving molecule** (LLM) called chlorophyll (Figure 1). The intense green color of chlorophyll helps the plant take up light energy and convert it into food. For PACT, instead of using chlorophyll like plants do, scientists make their own LLMs in the lab, in the form of colorful (green, blue, purple, etc.) dyes. The crucial thing about these dyes is that they can absorb light energy just like chlorophyll does, but in PACT, instead of making food, the colorful dyes transform light energy into tiny "bullets" known as **reactive oxygen species** (ROS) that can damage harmful microorganisms.

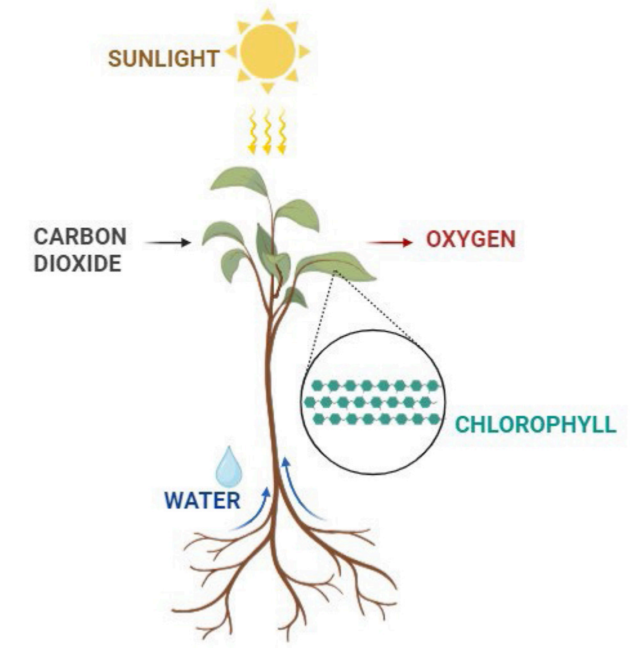


Figure 1

Figure 1

In the process of photosynthesis, plants use a light-loving molecule called chlorophyll to take up energy from sunlight and, in the presence of carbon dioxide and water, convert it into oxygen and food. For PACT, scientists make their own colorful molecules that can transform light into tiny "bullets" to fight harmful microorganisms (figure created by BioRender.com).

HOW DOES PACT WORK AGAINST INFECTIONS?

PACT begins when LLMs are deposited to the site in the body where the microorganisms are growing. Getting PACT into the right location can involve injecting the dyes or directly applying them to the infected area by using a cream or gel. At this stage, the LLMs do not harm the microorganisms. Next, scientists shine the right color of light on the area where the LLMs were placed, filling the LLM molecules with light energy and causing them to produce ROS (Figure 2). These ROS bullets can penetrate microorganisms and damage or destroy important structures, like the cell membrane and the DNA. Damage to the cell membrane causes the fluids inside the microorganisms to leak out, which leads to the death of the microorganisms. When microorganisms die, they can no longer cause disease, so the person feels better [2].

As long as the LLMs are receiving light energy, this process continues until all the microorganisms near the LLMs are dead. As an example, toothaches can be caused by bacteria growing around a tooth and causing an infection. LLMs can be injected into the gums in the infected area, followed by shining light on that area. The LLMs then produce tiny ROS bullets that are harmful to the microorganisms causing the dental infection. The microorganisms die, and soon the patient's toothache goes away (Figure 3).

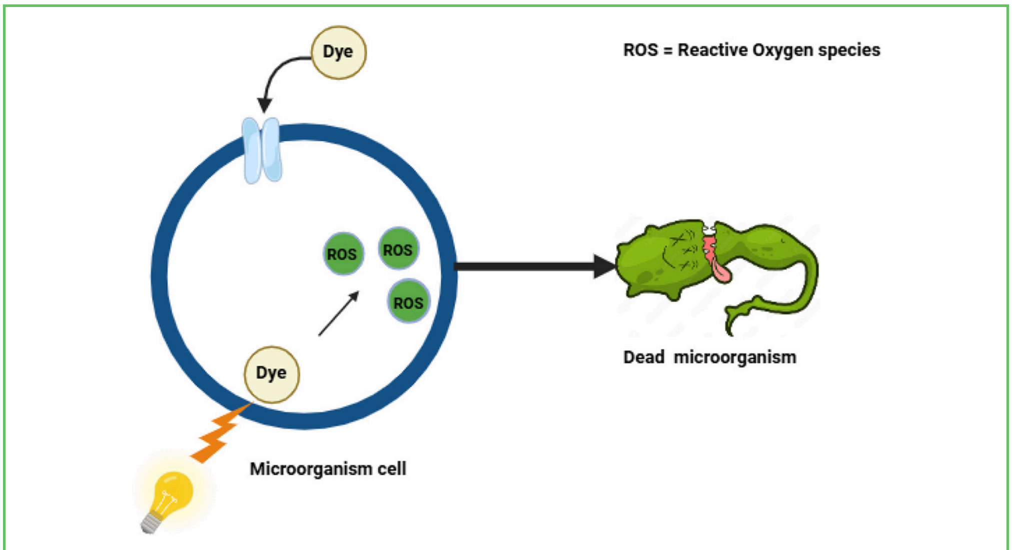


Figure 2

Figure 2

In PACT, LLMs are injected or applied to the body at the site of infection, so that these dyes will end up close to the infecting microorganisms or even inside them. Then, doctors shine the right color of light on the area, which energizes the LLMs and causes them to produce "bullets" called ROS. ROS can harm the microorganisms by making holes in the cell membrane, leading to the death of the microorganisms (figure created by BioRender.com).

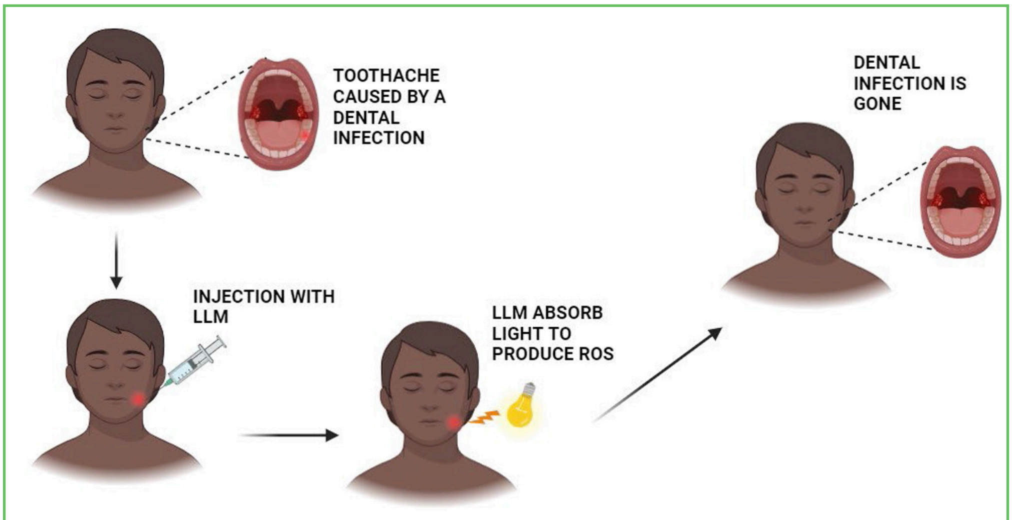


Figure 3

Figure 3

PACT can be used to treat a toothache caused by a dental infection (figure created by BioRender.com).

WHERE CAN WE USE PACT IN REAL LIFE?

PACT is not just an ordinary tool; it is a versatile warrior that can be used by doctors and scientists to fight sicknesses caused by harmful microorganisms that are difficult to treat with antibiotics. You can also imagine it as a healer, fighting off acne, skin infections, yeast infections like oral thrush, and even athlete's foot. But its capabilities do not stop there. Think about **parasites**—organisms that feed, grow, and reproduce inside other living things while causing them harm. Parasites cause diseases that lead to many thousands of deaths every year. PACT shows promising results in fighting against parasitic diseases including Chagas disease, malaria, leishmaniasis, and trypanosomiasis [4].

PARASITES

Organisms that feed, grow, and reproduce inside other living things while causing them harm.

But what about viruses? To date, viral infections have no cure. However, PACT might be able to control viral infections such as herpes, influenza, and HIV. It cannot make viral infections disappear completely, but it can weaken the viruses, helping the immune system to fight them. Interestingly, PACT might also be effective against COVID-19, as well as dental, eye, respiratory, and stomach infections [5]. And do not forget those stubborn antibiotic-resistant bacteria [6]. PACT is ready to face the challenge of combating antibiotic resistance and protecting us against dangerous evolving microorganisms [7]. The wonders of PACT do not just end with humans it can also be used to fight diseases that affect animals, such as dogs and horses.

ADVANTAGES AND LIMITATIONS OF PACT

PACT has many advantages compared to the commonly available antibiotics used to treat bacterial infections. For example, unlike some antibiotics that kill beneficial bacteria along with harmful ones, PACT can target only harmful microorganisms because it can be delivered strictly to the infected area. Unlike antibiotics, which can lead to resistance, PACT does not make microorganisms stronger over time, and no resistance has been reported against PACT. The dyes used in PACT are relatively safe for the human body, in both the presence and absence of light, which limits the possibility of the treatment itself causing harm. Additionally, the dyes can be reused, making the technology less expensive and environmentally friendly. For example, if you have an infection outside the body the dye can be attached to surfaces of harmless objects or put in tiny carriers that carry them to the infected area. If the infection is inside the body the dyes are often designed such that they can be naturally eliminated by the body so that they don't cause further harm to patients. To achieve this, doctors utilize certain delivery systems or materials that can decompose safely.

But every hero has its challenges, and PACT is no exception. PACT is more effective in dealing with microorganisms that are found on the surface of the human body, but it might not work well against those that are deep inside. Moreover, patients may remain sensitive to light for a while after treatment, until the body has time to get rid of the dyes. The tools and dyes needed for PACT can be quite expensive, too. Finally, unlike antibiotics, which can be easily administered with an injection or an oral medicine, treatment with PACT requires doctors to follow several steps, including the administration of the dye at the infected area, introduction of light, and monitoring the progress of the treatment.

In conclusion, PACT combines light with dyes to wage war against diseases caused by harmful microorganisms. Dyes absorb light energy and convert it into small ROS “bullets” that attack and destroy microorganisms. However, doctors and scientists must be careful and think about how PACT might affect us (and other living things) in the long term. Scientists are still working to learn more about how PACT works, and they are conducting tests to ensure that it is safe and effective for everyone.

ACKNOWLEDGMENTS

This work was supported by the Institute for Nanotechnology and Water Sustainability (iNanoWS), College of Science, Engineering and Technology (CSET), University of South Africa, South Africa.

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SUBMITTED: 28 January 2024; **ACCEPTED:** 24 June 2024;
PUBLISHED ONLINE: 16 July 2024.

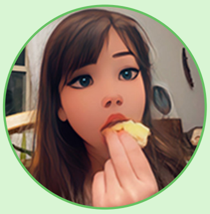
EDITOR: Valeria Costantino, University of Naples Federico II, Italy

SCIENCE MENTORS: Monica Cartelle Gestal and Patricia Welch Saleeby

CITATION: Managa M, Moraba TGT, Malomane N and Nene K (2024) A New Way to Treat Diseases Using Light-Loving Molecules. Front. Young Minds 12:1377991. doi: 10.3389/frym.2024.1377991

CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS



ARIANA, AGE: 8

Ariana loves to know how the body works. She is always curious. She is fascinated about learning all she can about how to improve humans and animals' lives. She is passionate and enthusiastic. One of her favorite things to do is sitting down on the sofa looking at books or videos about the body or about animals. She wants to be a vet when she grows up.

KABIR, AGE: 12

Hi, I am Kabir. I am 12 years old. My favorite food is butter chicken. I enjoy playing Fifa and playing outside. My Favorite hobbies include: soccer, basketball, and football. My favorite subjects are Science and P.E because it allows me to do what I am good at and take a break from all of my stressful activities including my core classes. Each year I do a science project to showcase what I know and bring my ideas to life.

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NONKULULEKO MALOMANE

Nonkululeko Malomane is a Master of Science candidate at the Institute for Nanotechnology and Water Sustainability (iNanoWS), University of South Africa (UNISA). She holds her Bachelor of Science Honors in Chemistry degree from the University of Venda. Her current research focuses on the use of light-loving molecules combined with tiny matter for getting rid of bacteria for applications in water storage systems.

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Kwanele Simo Nene is master's student in chemistry at the Institute for Nanotechnology and Water Sustainability, University of South Africa (UNISA). He holds his honors degree in chemistry from the University of KwaZulu-Natal. His research project is based on photoinactivation of bacteria in water using dyes (porphyrin) conjugated to nanomaterials (bimetallic nanomaterials).

EARTH SCIENCES
Published: 27 November 2024
doi: 10.3389/frym.2024.1355364

DO NANOPARTICLES AFFECT CROP GROWTH AND SOIL BACTERIA?

***Busiswa Ndaba*[1*], *Haripriya Rama*[2] and *Ashira Roopnarain*[2,3]**

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YOUNG REVIEWERS:

OFUNWA
AGE: 9

VUSANI
AGE: 10

Did you know scientists can make tiny structures called nanoparticles, which are smaller than the smallest ants? Nanoparticles are useful for a lot of different things, including helping farmers grow our food crops. Without fertilizers, which are nutrients applied to gardens and farms to help crops grow, it would be difficult to grow enough vegetables and fruits to support all the humans on Earth. However, some fertilizers are too big to be easily taken up by plants. Because nanoparticles are so tiny, they can easily get into plants and help them grow. But there is a downside—sometimes nanoparticle fertilizers disturb the growth of natural organisms in the soil, such as bacteria. Some soil bacteria also help plants to grow, so they need to be protected. It is therefore important to understand how nanoparticle fertilizers affect the bacteria in the soil.

WHY DO WE NEED FERTILIZERS?

By 2050, there will be more than 9.7 billion people on the planet [1]. To feed all these people, farmers will need to produce more food than they do today. To ensure that no one goes hungry, we need to come up with farming techniques that both produce lots of food *and* are safe to the environment. Farmers generally use **fertilizers** to help their crops grow. Fertilizers provide important nutrients that plants need to thrive. The problem is that the common chemical fertilizers that farmers use consist of large particles, which generally do not enter plants very easily because of their size. As a result, during heavy rains and floods, these fertilizers are washed out of fields and into waterways, like rivers and groundwater. This can be bad for the environment and unhealthy for humans [2]. Good farming methods require fertilizers that are fully used by the plant, with less washout during rains.

FERTILIZER

A natural or factory-made product containing chemical elements such as nitrogen, phosphorus and potassium, which act as food for plants and help them grow.

Nanoparticles are very tiny particles that are measured in nanometres. A million nanometres is equal to a single millimeter (mm), so nanoparticles are much smaller than the smallest known ant, which is about 1 mm long (Figure 1). Nanoparticles have been used in several kinds of industries [3]. For example, nanoparticles can be found in medical test equipment and cleaning solutions like detergents, because they can fight germs. Nanoparticles are also used in agriculture as nanopesticides to protect crops and as nanofertilizers to help them grow. Because of their tiny size, nanoparticles can enter crop plants more easily than traditional fertilizers can, so they can be used to efficiently deliver nutrients that boost plant growth [3]. When used in this way, they are called **nanofertilizers**. If they are taken up by plants more easily, nanofertilizers might have less washout, which means these fertilizers could be less harmful for the environment.

NANOPARTICLES

Tiny structures that have a size range between 1 and 100 nanometres. One nanometre is 1/1,000,000 of a millimeter.

NANOFERTILIZER

A fertilizer formulated with nanoparticles to help the plant grow

Figure 1

Figure 1

Nanoparticles are measured in nanometres (nm), with one nanometre being one millionth of a millimeter (mm). The smallest known ant is 1 mm in length.

However, not all nanoparticles can act as fertilizers as some nanoparticles can be too dangerous for the plant. In most cases, the nanoparticles that are mostly helpful in plants are those that are known nutrients such as zinc, iron and others. Some nanoparticles such as silver and titanium are used to clean contaminated water and can also be incorporated in membranes or filters to allow the water to pass through for purification.

The use of nanoparticles as nanofertilizers is very helpful however, there is another factor farmers must consider in their choice of fertilizers—microorganisms that live in the soil, such as **bacteria**. Soil contains bacteria that are both good and bad for crops. Bad bacteria can delay or stop plant growth, while good bacteria can help plants grow by making nutrients available to them. When nanofertilizers are used, they might affect the growth of bacteria in the soil [4]. We did not know whether nanoparticles would inhibit or improve the growth of soil bacteria, so we decided to do an experiment to test this.

BACTERIA

Living organisms that are found everywhere on the planet but cannot be seen with the naked eye, only through a microscope.

HOW DO NANOPARTICLES AFFECT SOIL BACTERIA?

First, we studied the effect of nanoparticles made of a substance called iron oxide on a type of bacteria called *Bacillus subtilis*. *Bacillus subtilis* can be grown in the laboratory, so it is easy to do experiments on, but this type of bacteria was also chosen because it is found in soil, where it is good for plant growth. The experiment was done by growing *Bacillus subtilis* on a culture plate containing nanoparticles along with the nutrients that the bacteria need to grow.

To clearly show whether nanoparticles negatively affect bacteria, we needed to include a **control** in our experiment—something that was *known* to have an effect on bacteria, so that we would have something to compare the effect of nanoparticles to. Antibiotics are medicines doctors use to kill bacteria, so we placed small discs of paper soaked in antibiotics on our control culture plate. In Figure 2A, you can see the clear zones around the antibiotic discs where the bacteria cannot grow. No clear zones (cloudy surface) around the discs mean bacteria can still grow, and this is what we saw in the presence of our iron oxide nanoparticles (Figure 2B), meaning that these nanoparticles did not hinder the growth of *Bacillus subtilis*.

CONTROL

Part of an experiment that shows the expected result, proving the experiment setup works. It helps scientists compare and confirm their results.

HOW DO NANOPARTICLES AFFECT SEEDS?

We also wanted to test whether seeds could still **germinate** in the presence of the iron oxide nanoparticles. This was done to prove whether the nanoparticles can also act as a fertilizer. To test this, we placed carrot seeds on damp filter paper in culture dishes, either with or without nanoparticles. As our control, we did the experiment with water alone and with no addition of the nanoparticles, as shown in Figure 3A. We found that the nanoparticles in Figure 3B were able to improve germination of carrot seeds compared to the control test without nanoparticles in Figure 3A. The length of the overall plant when nanoparticles were used increased to 82 mm, while the length of the plant when water with no nanoparticles was used increased

GERMINATION

The development of a seed to form a plant, also called sprouting.

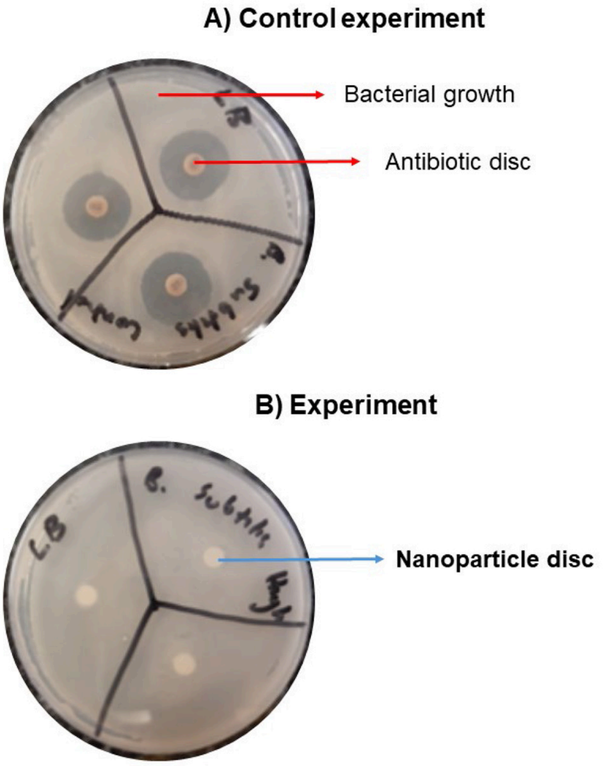

Figure 2

Figure 2

(A) As a control for our experiment, we used small discs soaked in antibiotics, which kill/prevent the growth of bacteria. You can see the clear circle around the discs where bacteria cannot grow. **(B)** To test whether nanoparticles affected the growth of bacteria, we used tiny discs soaked in nanoparticles instead of antibiotics. No clear circle around the discs prove that the nanoparticles did not stop the bacteria from growing. This tells us that nanoparticle fertilizers might be able to help plants grow without harming helpful soil bacteria.

to 27 mm. Both seeds in Figures 3A, B were germinated for 12 days. This means that even though plants can still grow using water alone for germination, adding nanoparticles for seed germination of carrot can increase the growth of the plant 3 times in comparison to using water alone.

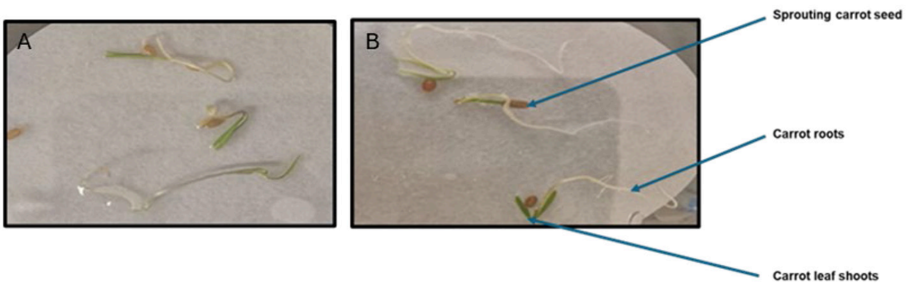

Figure 3

Figure 3

(A) Germination of carrot seeds on filter paper soaked in water without nanoparticles, **(B)** Germination of carrot seeds on filter paper soaked in water containing nanoparticles. Germination was done for 12 days. The seeds grown in nanoparticle solution grew much taller than the ones grown in just water, this shows that nanoparticles can improve seed germination thereby helping plants grow.

WHAT CAN WE LEARN FROM THESE RESULTS?

To feed the increasing number of people in the world, it is important to test new ways of promoting crop growth that are safe for the environment. We tested nanoparticles to understand whether they can help carrot seeds germinate and grow faster. We also looked at the effect of nanoparticles on a helpful type of soil bacteria, *Bacillus subtilis*. This was done because we need to know if nanoparticles are used as fertilizers, will they affect the growth of helpful microorganisms in soil. We discovered that small amounts of nanoparticles can help carrot seeds to germinate faster, and that the nanoparticles did not harm the bacteria. These results show that it might be safe to use low amounts of nanoparticles as nanofertilizers to promote plant growth.

ACKNOWLEDGMENTS

We acknowledge L'Oréal-UNESCO FWIS Programme and National Research Foundation (NRF); Grant numbers (121924 and 129651). The Agricultural Research Council (ARC) is also acknowledged for the support provided to undertake this research. Opinions expressed and conclusions reached are those of the authors and not necessarily endorsed by L'Oréal-UNESCO, NRF and ARC.

ORIGINAL SOURCE ARTICLE

Ndaba, B., Roopnarain, A., Vatsha, B., Marx, S. and Maaza, M. 2022. Synthesis, characterization, and evaluation of artemisia afra-mediated iron nanoparticles as a potential nano-priming agent for seed germination. *ACS Agric. Sci. Technol.* 2:1218–29. doi: 10.1021/acsagscitech.2c00205

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SUBMITTED: 08 January 2024; **ACCEPTED:** 06 November 2024;
PUBLISHED ONLINE: 27 November 2024.

EDITOR: Tarryn Lee Botha, University of Johannesburg, South Africa

SCIENCE MENTORS: Refilwe Lukhwareni and Nonhlangabezo Mabuba

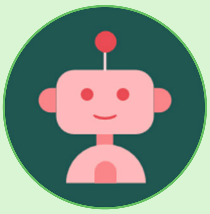
CITATION: Ndaba B, Rama H and Roopnarain A (2024) Do Nanoparticles Affect Crop Growth and Soil Bacteria? Front. Young Minds 12:1355364. doi: 10.3389/frym.2024.1355364

CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

OFUNWA, AGE: 9

He is a bright and bubbly 9-year-old with an infectious enthusiasm for life. Talkative and sweet, he can chat endlessly about his favorite video games, sharing tips and tricks with anyone who will listen. His intelligence shines through in his love for reading, Whether he is immersed in a game or exploring a new book, his curiosity and kindness make him a joy to be around. He always tries to find interesting facts about different planets and the entire solar system.



VUSANI, AGE: 10

Vusani is 10 years old and is attending Weltevreden Park Primary School. He is in grade 5 and loves to do Maths. He reads about theories to test if they are facts. He creates his own fantasy world by telling new stories to his friend and drawing characters. On Saturdays, he visits the library to read about the new comic books. He likes to play football and TV games with his brother and sister.

AUTHORS

BUSISWA NDABA

Busiswa Ndaba is a senior lecturer at the University of South Africa, College of Science, Engineering and Technology, South Africa. Her research focuses on producing nanoparticles in the laboratory for their use in the production of renewable energy (biogas, bioethanol, biobutanol) as well as in agriculture as fertilizers for a circular economy. Her interests are in developing sustainable methods for the energy and agricultural sectors. Busiswa likes hiking, reading, watching movies, and having a good time with family. *ndabab@unisa.ac.za

HARIPRIYA RAMA

Haripriya Rama is a researcher at the Agricultural Research Council-Natural Resources and Engineering, South Africa. Her research study focuses on the effect of two nanoparticles produced via greener methods on biogas production and digester microbial communities. Her research interests are in developing sustainable solutions to clean the environment via anaerobic digestion and exploring the potential capabilities of microorganisms. Haripriya enjoys reading, hiking, and spending time with family and friends.

ASHIRA ROOPNARAIN

Ashira Roopnarain is a microbiologist whose research focuses on renewable energy generation from organic wastes. She is particularly interested in how to improve biogas production in low-cost anaerobic digesters using cost effective and environmentally friendly methods. Ashira is a senior researcher at the Agricultural Research Council of South Africa. Outside work, Ashira enjoys spending time with her family, reading, gardening, and traveling.

ENGINEERING AND TECHNOLOGY
Published: 11 July 2024
doi: 10.3389/frym.2024.1356411

FILTRATION: MAKING DIRTY WATER CLEAN ENOUGH TO DRINK

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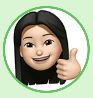
Institute for Nanotechnology and Water Sustainability, College of Science, Engineering and Technology, University of South Africa, Florida, South Africa

YOUNG REVIEWERS:


LEON
AGE: 12


STEPHANIE
AGE: 13

Water is needed for almost every aspect of human life: cleaning, drinking, and crop production. Membrane filtration is an effective way to remove the pollutants from water. Tiny holes in the membranes allow water to pass through while trapping dirt, bacteria, and other pollutants. Most water-filtration membranes can remove large pollutants such as hair, dust particles, and bacteria, as well as pollutants that cannot be seen with the naked eye, such as dissolved salts. In this article, we will tell you how membranes are made and how they can be used to make water clean and safe enough for people to drink.

THE WORLD NEEDS CLEAN WATER!

Of the total amount of water available throughout the world, only 3% is safe for human consumption. This water is available in the form of surface water (rivers and lakes) and underground water (wells and springs). The remaining 97% is in the oceans and not suitable for humans. Available fresh water has decreased over time due to the increase in populations and industries (especially pharmaceuticals, manufacturing, mining, and agriculture). The reduced availability of good-quality fresh water means that the world needs to study and develop advanced water-treatment technologies to enable the safe reuse of wastewater. Wastewater refers to water that has already been used and therefore contains harmful impurities called **pollutants**—for example, water from your kitchen or laundry.

POLLUTANTS

Substances or chemicals present in water making it not fit for its intended purpose.

Drinking water polluted with microorganisms can result in diseases such as cholera, diarrhea, and many more. With the increases in both human populations and the use of medications, new kinds of pollutants that are difficult to remove or break down into less toxic substances have become a problem in most wastewater treatment facilities. This has led to concerns about the consumption of these substances and what our digestive systems produce after interacting with them, since their health effects are often unknown [1]. As a result, research is being conducted to develop better wastewater treatment systems, so that people can have access to safe, treated water.

Membrane filtration is a method used to remove pollutants such as the salts in ocean water, dyes in wastewater from the textile industry, dirt from ground and surface water, and many more. The effectiveness of membrane filtration allows for water recycling, which can help reduce water shortages. Recycling water is good for the environment and helps to preserve the small percentage of Earth's available water.

MEMBRANE FILTRATION

A process by which impurities are removed from a fluid, either a liquid or a gas, using a sheet with pores in it.

MEMBRANE FILTRATION: REMOVING DIRT FROM WATER

A membrane is a barrier with tiny holes called pores that are not visible to the naked eye but can be seen under a microscope. The pores are mostly only nanometres in diameter (a nanometre is one billionth of a meter), and they allow water to pass through while preventing the passage of pollutants. You can think of membrane filtration like sifting something through a mesh or a screen. The mesh keeps large particles on one side while letting small ones through. In membrane filtration, the membranes are classified into classes with respect to their pore sizes: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO) [2]. The pore sizes get smaller in order from MF through RO. Membranes can remove pollutants ranging from those that can be seen with the naked eye (like dust particles and lint) to nano-sized particles (bacteria and proteins) and dissolved salt ions that cannot be seen (Figure 1). The amount of pressure that is used to drive water through the pores is another condition that makes filtration membrane types different from each other.

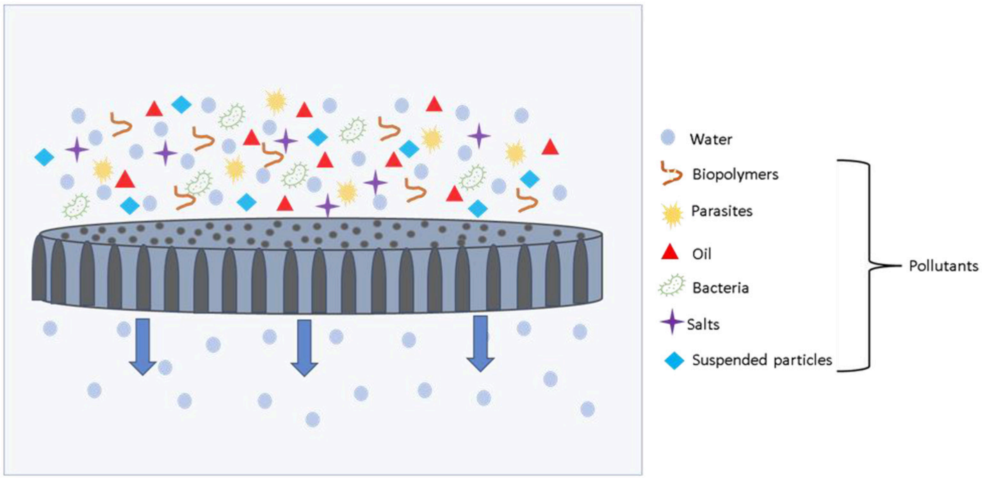


Figure 1

Figure 1

A membrane sheet sifting out unwanted pollutants (various colored shapes) from water during the filtration process. Membranes can remove all sizes of pollutants, from large pollutants like particles of dirt and parasites, all the way down to tiny salt molecules. The water can move through the holes in the membrane and come out clean on the other side.

FOULING

Deposition of pollutants on the membrane surface and pores, hindering water passage.

BACK-WASHING

Passing clean water or chemicals through the membrane in the opposite direction of water treatment, dislodging the deposited pollutants.

PRE-TREATMENT

The process of removing or reducing pollutants in wastewater before cleaning it with another treatment system such as chemical flocculation.

FLOCCULATION

The use of chemicals that are like magnets, to cause dirt and particles to stick together and form clumps that settle out of the water.

FOULING: WHEN MEMBRANES GET CLOGGED

Due to size variation, some pollutants can fit through the pores of the membranes and attach to the pore walls, building up there and blocking the pores. **Fouling**, defined as the blockage of the membrane pores by the pollutants in the water, is of major concern in membrane filtration. Blockage of pores slows down and ultimately prevents water from passing through the membranes. To minimize the accumulation of pollutants on the surface of the membranes and within their pores, a technique called **back-washing** is used. During back-washing, high-pressure clean water is run in the opposite direction to the filtration direction, pushing the pollutants off the membrane surface and out of the pores. Some pollutants, however, attach strongly to the membrane surface, forming a chemical linkage with the membrane [3]. In such cases, chemicals are used to break the linkages during back-washing. Membrane fouling can cause physical damage to the membrane, decreasing water quality and reducing the rate at which water passes through the membrane. This shortens the amount of time that membranes can be used, which leads to the need to frequently replace them.

One of the easiest ways to reduce membrane fouling is to start with another pollutant-removing method, called **pre-treatment** of water. Pre-treatment removes or reduces the pollutants that can cause fouling. One pre-treatment processes involves the addition of chemicals that cause the pollutants in water to stick together and form clumps that settle out of the water, which is called **flocculation**. Not only does pre-treatment prevent clogging, but it can also remove ∼70% of the pollutants, even the smallest ones, which means the membrane only has to remove the remaining pollutants, thereby producing higher-quality water. Wastewater that is pre-treated has low fouling potential, so membranes can be used for a longer period.

POLYMERS

Very large molecules made up of many smaller molecules called monomers, linked together in a repeating pattern. Plastic is an example of a polymer.

MIXED-MATRIX MEMBRANE

Membranes made of organic polymer containing inorganic nanomaterials to control the membrane properties.

NANOMATERIAL

Substances with sizes between 5 and 100 nm in at least one dimension.

HOW ARE MEMBRANES MADE?

Membranes are made of different kinds of materials: sand/clay particles for ceramic membranes, **polymer** materials for polymeric membranes, and specific metals, such as palladium, for metallic membranes. Recent developments involve mixing various membrane-making materials to make new membranes that are more effective or selective for removing just certain pollutants. These are called **mixed-matrix membranes**.

The process of making membranes is quite easy. The first step is to make a solution containing a polymer, a liquid called a solvent, and **nanomaterials** to control the properties and behavior of the membranes. This solution is often referred to as a dope solution (Figure 2A). Next, the dope solution is spread on a sheet of glass using a flat piece of metal called a casting knife (Figure 2B), and the dope-covered glass plate is then placed in a container of water (Figure 2C). After a few minutes, the dope solution changes to a solid form, creating a flat sheet of membrane (Figure 2D). Figure 3 shows how membranes appear under a microscope.

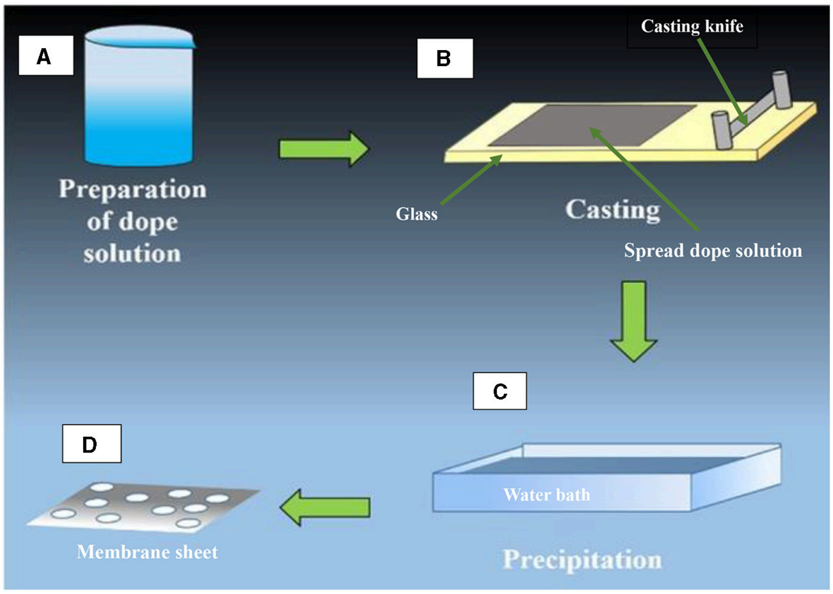


Figure 2

Figure 2

Steps in the preparation of a flat-sheet membrane. **(A)** A polymer powder is dissolved in a liquid (solvent) to make a dope solution. **(B)** The dope solution is spread on a sheet of glass using a solid, flat piece of metal called a casting knife. **(C)** The glass with the dope solution spread on it is then immersed in water bath, which causes the solution to change from a liquid state to a solid state. **(D)** The solid plastic-like membrane sheet with pores is then complete [4].

SUMMARY

Different types of filtration materials are used to clean dirty water, producing water that is clean and safe to drink. This is important because reusing treated water can supplement available clean water suitable for safe use. Commonly used membranes are made from polymers because they are generally less expensive to produce and easier to handle than ceramic-type membranes. Combining filtration with pre-treatment processes generally results in longer membrane

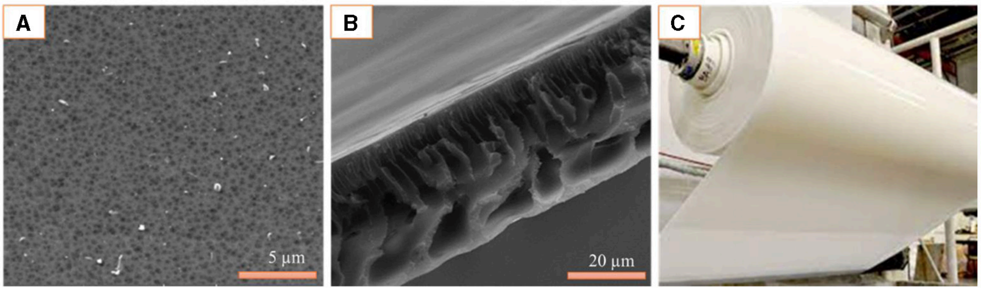


Figure 3

Figure 3

(A) A view of the top surface of a membrane through a microscope, with the pores appearing as dark, spot-like structures. **(B)** A microscopic cross-section or side-surface image, showing the empty tunnels of the membrane pores. **(C)** A roll of flat-sheet polymer membrane [5].

life and reduces the overall cost of wastewater treatment over the long term. Currently, membranes are the most efficient process in turning wastewater treatment into drinkable water, as well as for removing the salt from seawater.

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SUBMITTED: 15 December 2023; **ACCEPTED:** 24 June 2024;
PUBLISHED ONLINE: 11 July 2024.

EDITOR: Muthumuni Managa, University of South Africa, South Africa

SCIENCE MENTORS: Jing Li and Junhong Chen

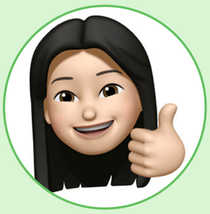
CITATION: Raseala MJ, Motloutsi ML, Matebese F and Moutloali RM (2024) Filtration: Making Dirty Water Clean Enough to Drink. Front. Young Minds 12:1356411. doi: 10.3389/frym.2024.1356411

CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

LEON, AGE: 12

Leon is 12-year old, enjoying reading and astronomy. He plays piano and enjoys doing math in his free time. He is curious and passionate about science and engineering in general and is a critical thinker. He has been doing internet research on science, engineering, and technology topics. Leon also likes hands-on experience, with many creative kitchen activities these days. His broad knowledge base at his age in combination with his keen scientific curiosity makes him a highly valuable young reviewer.



STEPHANIE, AGE: 13

My name is Stephanie and I am 13 years old. I am a 7th grader in middle school and my hobbies include singing, playing tennis, and playing the clarinet. My favorite subject in school is ELA and I enjoy reading and writing mystery and dystopian stories. I have performed for the UniverSoul Circus before and I have been a reviewer for some scientific articles in this journal.

AUTHORS

MABORE JERIDA RASEALA

Miss Mabore started her journey at the University of Limpopo, where she received a B. Sc. in physical sciences. She then received honors in chemistry at the same school. Upon completion, she earned a M. Sc. in applied chemistry at the University of Johannesburg. She was then appointed as a Golden Key candidate at the same university. Currently, she is a Ph. D. candidate at the University of South Africa, Institute for Nanotechnology and Water Sustainability, where her research focuses are wastewater reclamation, membrane technology, and flocculation. Throughout her studies she received financial support from NRF, Sasol, Mintek, and an award from Phatsima.

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Miss Motloutsi graduated from the University of Limpopo in 2017 with a B. Sc. in chemistry and biochemistry and a B. Sc. with honors in chemistry, respectively. Then, with funding from DSI/Mintek NIC, she completed her master's degree at the University of Johannesburg in 2019. She is currently enrolled with the University of

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Dr. Matebese holds a B. Sc. in chemistry and geology from the University of Fort Hare. She was awarded the Sasol-Inzalo Foundation together with an NRF scholarship to pursue her honors and M. Sc. degree in chemistry at the same university. In 2019, she enrolled for a Ph. D. at the University of Johannesburg and was awarded a DSI/Mintek NIC and NRF scholarship. She visited Nanjing University of Technology, China, in a student exchange program, from December 2019 to February 2020. She is currently a postdoctoral researcher at the University of South Africa, where her research focuses on membrane technology and wastewater treatment.

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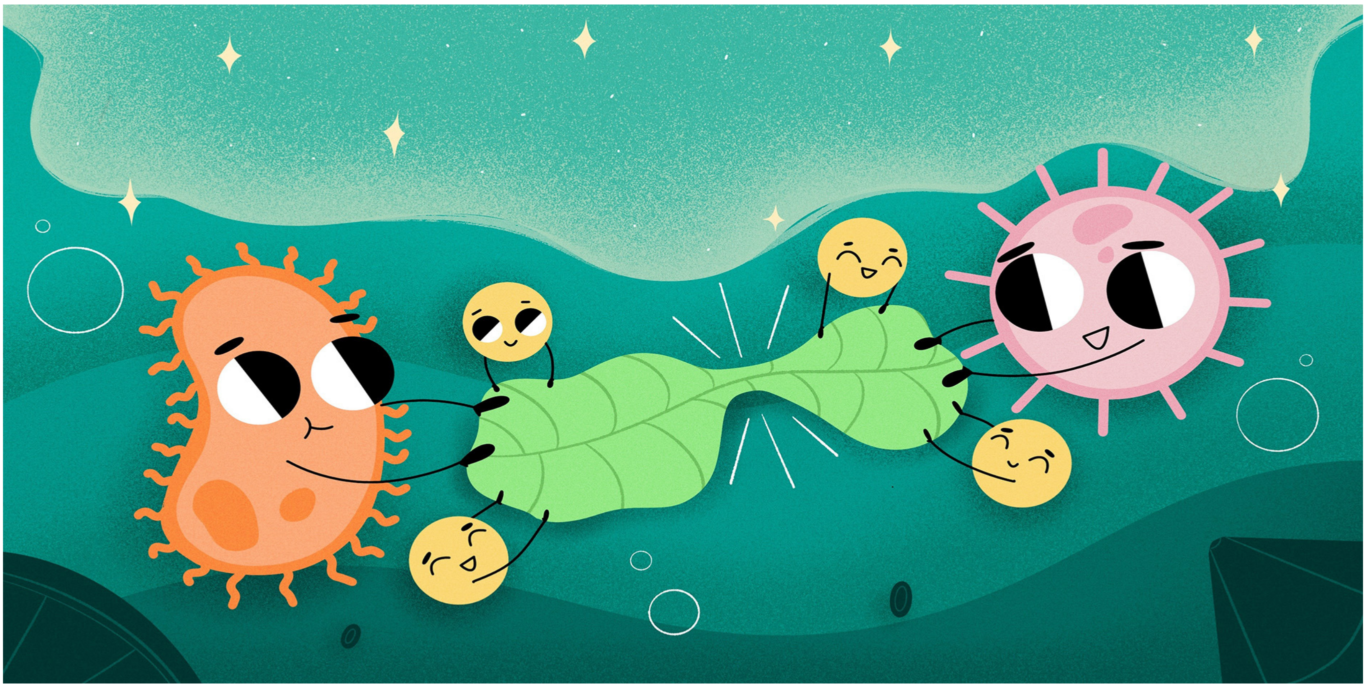
ENGINEERING AND TECHNOLOGY
Published: 31 July 2024
doi: 10.3389/frym.2024.1354574



CAN NANOPARTICLES BE USED TO BOOST BIOGAS PRODUCTION?

Ashira Roopnarain [1,2*], ***Haripriya Rama*** [1,3] ***and Busiswa Ndaba*** [4]

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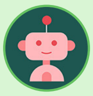

KIANA

AGE: 9

OFUNWA

AGE: 9

Biogas is a type of gas that can be burnt to produce energy. It causes less harm to the environment than burning coal or oil, which is why it is called "green energy". Biogas is produced by breaking down a plant or animal resource such as cow dung (poop) in an oxygen-free environment. Biogas is produced by special microorganisms that can survive and multiply without oxygen. Recently, nanoparticles have been used to make more biogas. Nanoparticles have unique features such as their extremely small size and their ability to easily react with substances. During biogas production, microorganisms can get a lot of nutrients from nanoparticles, which helps them to produce more biogas. Nanoparticles may also improve the interactions between biogas-producing microbes, further boosting biogas production.

Although nanoparticles help to produce more biogas, the correct type of nanoparticles and the right amounts must be used to ensure that more biogas is produced.

BIOGAS: GREEN ENERGY GENERATION AND WASTE MANAGEMENT

Around the world, humans need energy to perform their daily activities. This energy is required to power our ovens, microwaves, and computer screens, just to name a few. As more children are born, increasing Earth's population, more and more people will need energy. To date, energy is mostly produced from resources that cannot be produced again, like coal and oil. These energy sources are sometimes called **non-renewable resources** because, as we use them, they are not being replaced. Burning non-renewable resources releases gases into the air, called greenhouse gases, which are harmful to the environment and can cause shifts in normal temperatures and weather patterns. This is called global warming.

Renewable energy resources, which are resources that are continuously created, are a great alternative because they provide "green energy" for human uses. Green energy includes energy from the sun, water, wind, and **biomass** [1]. Biomass energy created from waste material (like cow poop or crop waste) is particularly interesting. It results in green energy production and makes use of waste, which is a win-win situation. If waste is used to produce energy, this means less waste and more energy.

Organic wastes are waste products that can be broken down by microbes—microscopic organisms that cannot be seen by the naked eye, such as bacteria, viruses, and fungi. Organic wastes can be used as a starting material to produce a substance called **biogas**, which can be burned for energy.

So, what is biogas and why is it such a promising green energy source? Biogas is made when organic waste is broken down by special microbes in an oxygen-free (**anaerobic**) environment. The biogas is rich in a gas called methane, which can be burnt for cooking, heating, and lighting purposes. It may even be used to power gas generators for electricity production. In nature, biogas is produced in the stomachs of animals like cows, because their stomachs are oxygen-free. Their stomachs also contain the microbes that can break down the grass that they eat into biogas. Scientists have built **bioreactors**, called anaerobic digesters (Figure 1), that essentially act as cow stomachs. Bioreactors produce biogas from various types of organic waste. The resulting biogas is removed through a pipe. Another outlet releases the leftover broken-down organic waste from the system. The extra waste can be used by farmers as a nutrient-rich fertilizer. Many methods have

NON-RENEWABLE RESOURCES

A substance that is extracted from the Earth, like coal, that cannot be replaced after it is used up.

RENEWABLE ENERGY RESOURCES

A substance that is continuously created and can be replaced naturally over time, like trees.

BIOMASS

A renewable organic material that comes from plants and animals.

ORGANIC WASTES

Any material that can break down in nature and comes from either a plant or an animal.

BIOGAS

A gaseous fuel, primarily made of methane, produced by the breakdown of organic matter by microbes.

ANAEROBIC

An environment that has no oxygen.

BIOREACTOR

A container or vessel where raw materials (such as organic wastes) are converted into products (such as biogas) by microbes or enzymes.

NANOPARTICLES

Very small particles that range between 1–100 nanometers in size.

been used to increase the amount of biogas produced in anaerobic digesters. One promising method is adding **nanoparticles** to the system [2].

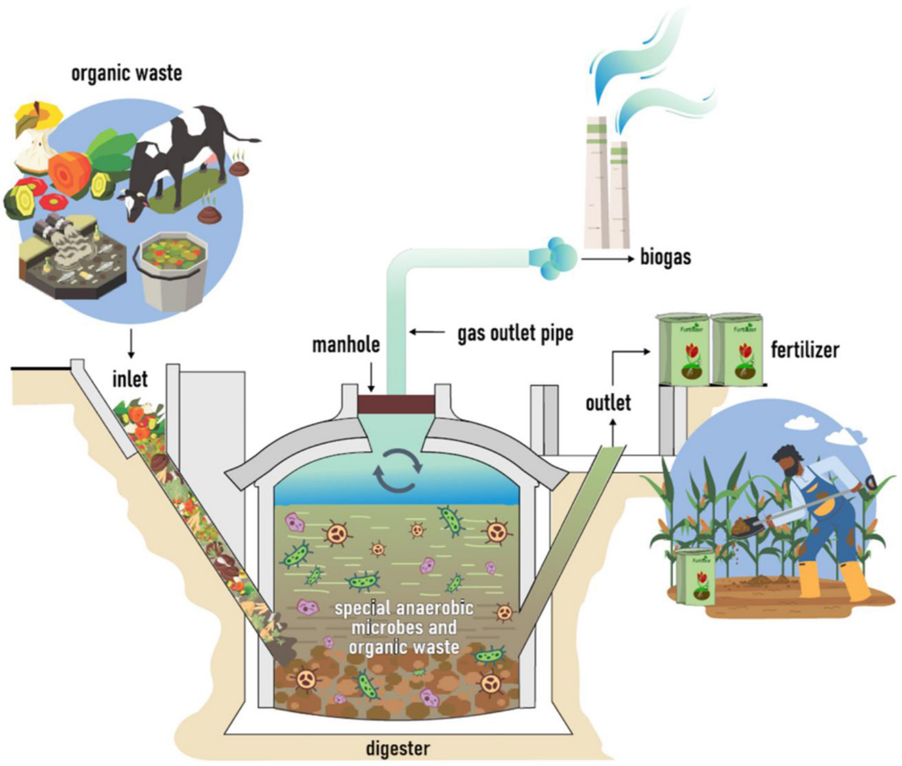

Figure 1

Figure 1

Biogas can be produced in a system called an anaerobic digester. Organic waste, such as cow poop and/or food waste, is added to the digester as a starting material. Microbes break down the organic waste inside the digester, in the absence of oxygen. Biogas is captured through a pipe, and the leftover digested organic waste leaves through an outlet and can then be used by farmers as fertilizer.

NANOPARTICLES CAN IMPROVE BIOGAS PRODUCTION

Nanoparticles are extremely small particles, <100 nanometers in size (Figure 2). Although nanoparticles are very small, they pack a lot of punch. Their small size gives them several special properties, such as high reactivity (ability of nanoparticles to interact with other substances) and high surface area-to-volume ratio (surface on the nanoparticle where reactions take place in relation to their size). These properties make nanoparticles promising candidates for improving biogas production [2].

Since biogas is produced by certain kinds of microbes, its production can be increased by helping these microbes to perform better. This is how some nanoparticles such as those made of iron, carbon, zinc, and nickel can improve biogas production [2]. They also improve microbial growth by acting as a nutrient source. Normally, a large group of microbes work together as a team to produce biogas. Anything that negatively affects any member of the team can slow down biogas production. Some nanoparticles help certain microbes in the group interact with others to speed up the breakdown of organic waste to biogas.

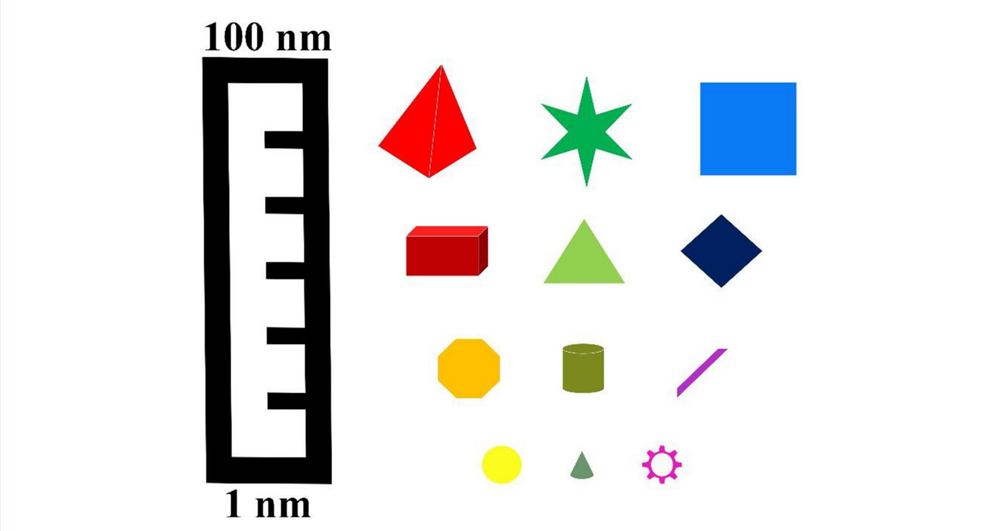

Figure 2

Nanoparticles come in various shapes and range between 1–100 nm in size.

Many studies have shown that certain nanoparticles can improve biogas production. Others have shown negative effects of nanoparticles on biogas production and the microorganisms that drive the process [3]. It is important that studies be conducted to test the effects of different types of nanoparticles on biogas production, to see which ones speed it up and which ones slow it down. The correct number (amount) of nanoparticles to use during biogas production also needs to be studied. It is also important to test whether the selected nanoparticles improve biogas yield no matter what type of organic waste is being digested.

USING NANOPARTICLES IS CHALLENGING

There are some problems related to using nanoparticles for improving biogas yield. The biggest problem is the impact the nanoparticles have on the environment after their use in the digester. In general, the digested waste from the system can be used as a fertilizer. However, can this still happen if the waste contains large amounts of nanoparticles?

The digested waste may be good or bad to the environment, depending on the types and amounts of nanoparticles that are added to the digester. Certain nanoparticles may be useful to the soil and plant growth and may even help maintain the nutrient levels of the soil. But other nanoparticles, in large amounts, may pollute the environment and may even result in the pollution of underground water reserves. Moreover, nanoparticles may be costly to produce, and producing them may also be harmful to the environment [1]. Like with any new technology, it is important that several studies be conducted in a controlled environment such as a laboratory.

These studies can ensure the safety of the product and improve production processes.

TAKE HOME MESSAGE

Overall, the world needs renewable energy sources due to the negative impacts of burning non-renewable fuels like coal, oil, and gas. Biogas is a promising renewable energy source that has two benefits—energy generation and waste management. However, the biogas production process needs to be improved, and nanoparticles show great potential for boosting its generation. While several studies have shown that more biogas is produced when nanoparticles are added to the system, other studies have shown negative effects on the process. Such findings are expected because the microbes involved in biogas production behave differently in response to different types and quantities of nanoparticles. Using nanoparticles to improve biogas production is still new and more studies are required to determine the effects of different nanoparticles on the microbes and biogas production. These studies will identify the ideal nanoparticles and amounts that need to be used to improve the process. Studies are also required to make sure that the nanoparticles do not negatively impact the environment when the digested organic matter from the system is used as a fertilizer. Finally, an environmentally friendly, cost-effective method of making nanoparticles is also needed. All in all, the potential for nanoparticles to improve biogas production cannot be questioned; however, as with any new technology, working out the details is key.

ACKNOWLEDGMENTS

We acknowledge the National Research Foundation of South Africa (NRF; Grant numbers 121924, 128307, 129651, and 128102) and the Agricultural Research Council (ARC) for the support provided to undertake this research. Opinions expressed and conclusions reached are those of the authors and not necessarily endorsed by the NRF and ARC.

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SUBMITTED: 12 December 2023; **ACCEPTED:** 15 July 2024;
PUBLISHED ONLINE: 31 July 2024.

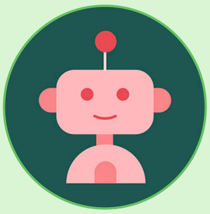
EDITOR: Tarryn Lee Botha, University of Johannesburg, South Africa

SCIENCE MENTORS: Refilwe Lukhwareni and Lourelle Neethling

CITATION: Roopnarain A, Rama H and Ndaba B (2024) Can Nanoparticles Be Used to Boost Biogas Production? Front. Young Minds 12:1354574. doi: 10.3389/frym.2024.1354574

CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS



KIANA, AGE: 9

Kiana is 9 years old. Kiana likes to do ballet as well as netball and hockey. Her favorite subject is maths.

OFUNWA, AGE: 9

Ofunwa is a curious young mind, who loves to learn new things and know more about our solar systems, history, and technology. He is currently in Grade 4 and would like to either be a web designer or musician. He loves playing Roblox and Fortnite on the Xbox or watch YouTube educational/entertaining videos. He loves researching new places that he travels to with his family and adores his family of 4.

AUTHORS

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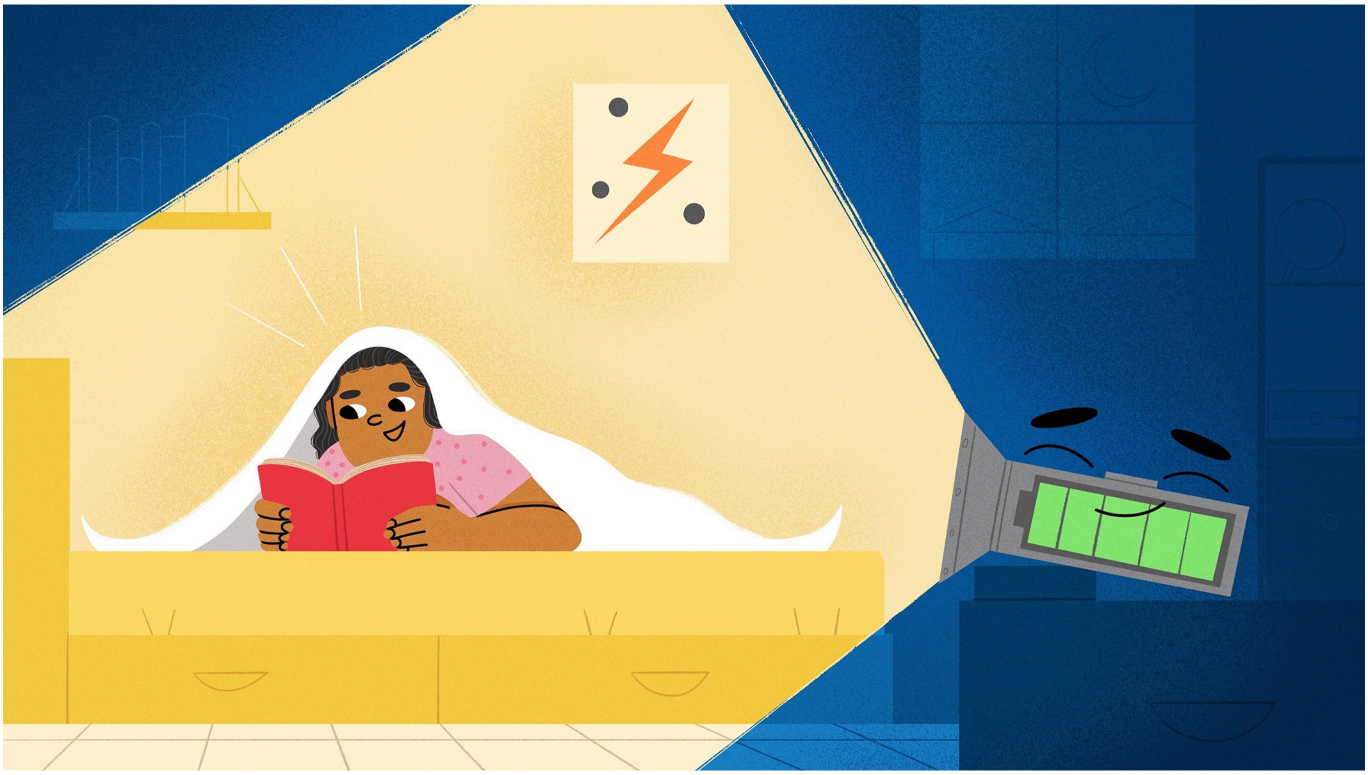
BUSISWA NDABA
Busiswa Ndaba is a senior lecturer at the University of South Africa, College of Science, Engineering and Technology, South Africa. Her research focuses on producing nanoparticles in the laboratory for their use in the production of renewable energy (biogas, bioethanol, and biobutanol) as well as in agriculture as fertilizers. Her interests are on developing methods that are sustainable for the energy and agricultural sectors. Busiswa likes hiking, reading, watching movies, and having a good time with family.

ENGINEERING AND TECHNOLOGY
Published: 05 September 2024
doi: 10.3389/frym.2024.1349295



USING NANOMATERIALS TO MAKE BETTER BATTERIES

Yared S. Worku[1*], *Ludwe L. Sikeyi*[1], *S. A. Olalerua*[1], *Nithyadharseni Palaniyandy*[1*], *Mkhulu M. Mathe*[1] *and Vijaya V. Srinivasu*[2]

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YOUNG REVIEWERS:

SAKINA
AGE: 15

ZI-AN
AGE: 9

Batteries are everywhere in our lives—from our phones and watches to cars and military equipment. Lithium ion batteries (LiBs) are a rechargeable kind of battery often used in common electronic devices. Researchers are working hard to improve batteries, so they can be used for longer without recharging and so they can store more energy—perhaps even energy from wind or solar sources that we can use to power our homes and businesses. Recent research has shown that LiBs can be improved by using extremely tiny materials with special properties, called nanomaterials. When they are used in LiBs, nanomaterials can increase the amount of energy that can be stored and decrease the amount of time it takes to recharge. Nanomaterials can also extend the life of LiBs. In this article, we

will explain how LiBs work and how nanomaterials might be used to improve their performance.

BATTERIES ARE ENERGY-STORAGE DEVICES

Fossil fuels, such as coal, crude oil, and natural gas, have long been the world's primary energy source. However, these fuels will eventually run out and, in the meantime, they are causing widespread pollution of the environment, through production of carbon dioxide (which contributes to global warming) and other dangerous substances. In the face of this challenge, there is increasing pressure to use environmentally friendly, renewable energy sources like wind and solar power. However, these sources do not produce power in a steady way that could support the world's energy needs. Communities need power all day and night, but the sun does not shine all the time and the wind does not blow constantly—so, there must be a way to store energy from renewable sources, so that it can be released as needed. **Electrochemical energy-storage** devices are one solution. These devices work by storing electricity through chemical reactions that happen inside them. When the sun shines or the wind blows, these devices capture the energy and keep it in a chemical form that can be turned back into electricity through additional chemical reactions whenever people need it, like at night or when the air is still [1]. There are various kinds of electrochemical energy-storage devices (Figure 1), which can provide dependable, long-term backup power for households, companies, data centers, and other needs.

ELECTROCHEMICAL ENERGY STORAGE

A way of keeping energy in chemical form inside batteries and other storage systems, which can then be turned into electricity when we need to power electronics or other devices.

Figure 1

Figure 1

There are various types of electrochemical energy-storage devices, all of which store and release energy through chemical reactions that happen inside them. While batteries are the most well-known of these devices, fuel cells, which generate electricity by combining hydrogen and oxygen to produce water and electrical power without needing to be recharged, and supercapacitors, which store electrical energy on the surface of materials and can charge and discharge much quicker than batteries (but hold less energy), are other examples. Reproduced with permission from [1]. Copyright 2020, MDPI.

BATTERIES: SINGLE-USE AND RECHARGEABLE

Batteries are probably the most well-known electrochemical energy-storage devices. A battery works as a kind of container that stores energy within the chemical compounds inside it, until the energy is needed. The chemical energy is converted into electric energy when the battery is used. Batteries can be classified as primary or secondary batteries. Primary batteries are intended to be used just once before being thrown away, while secondary batteries can be recharged and used repeatedly. Most primary batteries contain substances such as zinc and carbon, and they cannot be recharged because the chemical processes that happen inside them are irreversible. Primary batteries are sometimes called dry cells because most of them do not contain any liquids—just a paste-like substance. On the other hand, rechargeable or secondary batteries, such as lead-acid, nickel-cadmium, and lithium-ion batteries (LiBs), can be recharged several times and used repeatedly, since the reactions that happen inside them can be electrically reversed. There are multiple types of secondary batteries—some of them, like car batteries, have wet cells that contain a fluid that helps the electricity to move through them, while others, like the LiBs that power many portable electronic devices, have dry cells. Rechargeable batteries are becoming preferable due to the demands of the modern world and the rising number of portable devices [2].

ELECTRODE

A part of a battery where electricity goes in or out, helping to connect the battery's power to the things it runs.

SEPARATOR

A special layer within a battery that keeps the positive and negative sides apart to prevent short circuits, while still allowing electricity to flow through.

ELECTROLYTE

A substance that contains ions and can conduct electricity, often used in batteries to help move an electrical charge between the electrodes.

IONS

Tiny particles that carry an electric charge, either positive or negative, and are important in creating electricity in things like batteries.

HOW DO RECHARGEABLE LIBS WORK?

LiBs are found in many everyday household items like flashlights, cameras, toys, medical equipment, portable electronics, and security systems (Figure 2). These batteries can store a lot of energy for their size, hold on to that energy for a long time, and be successfully recharged many times. But have you ever wondered how they work? Imagine the battery as a sandwich. In this sandwich, there are two pieces of bread on either side called **electrodes**, one is positive (called the cathode), and the other is negative (called the anode). The "filling" between these pieces of bread includes a special material called a **separator** and a liquid called the **electrolyte** (Figure 3A).

The separator is a very thin layer that keeps the positive and negative sides from touching each other, which is super important for safety and for making sure the battery works properly. The electrolyte is a special kind of liquid that helps lithium **ions** (tiny charged particles of the metal lithium) move back and forth between the two pieces of bread when the battery is being used or charged [3]. In batteries, the separator material is made from a membrane with many microscopic holes in it. These membranes can be made of various substances, and the ones used in LiBs are chosen for their mechanical strength, chemical resistance, and heat stability.

When you use your phone, for example, and the battery is releasing power, lithium ions move from the negative side to the positive side through the electrolyte. This movement creates electrical energy that powers your device (Figure 3B). When you charge your phone, you are pushing those lithium ions back to the negative side, getting the battery ready to work again.

Figure 2

Figure 2

LiBs are used as power sources in many types of devices, such as smartphones, laptops, watches, torch lights, military equipment, aircraft, electric vehicles, and more.

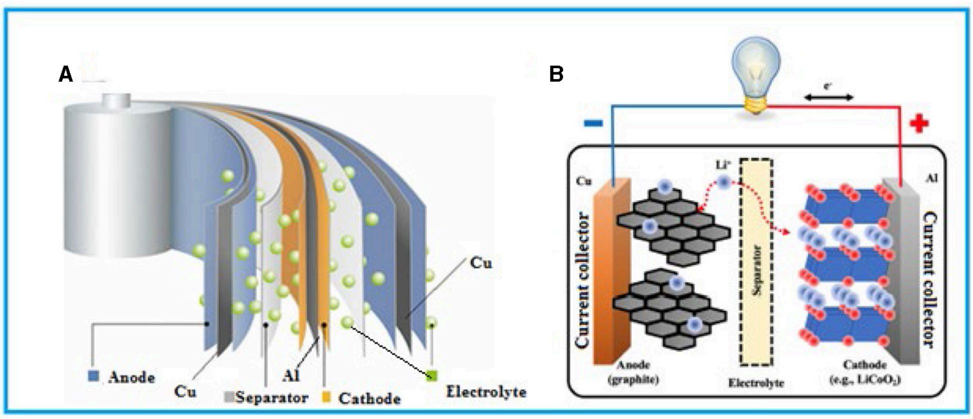

Figure 3

Figure 3

(A) The inside of a LiB looks kind of like a sandwich. The two slices of "bread" are the anode and cathode. They are kept apart by the "filling"—a special material called the separator, which allows ions to flow through but stops the anode and cathode from touching. **(B)** Within the battery, the lithium ions (Li^{+}) move from the anode through the separator to the cathode when power is needed and back to the anode when the battery is recharged. Movement of ions from the anode to the cathode makes electricity, in the form of electrons, move through wires, which powers the device [4].

The materials for the electrodes are also chosen based on their properties. The cathode must be positively charged and really good at attracting electrons, while the anode must be negatively charged and great at releasing electrons. This difference is why electricity flows in the battery, and why your phone turns on and works. Common materials used for the electrodes are graphite (a form of carbon) for the negative side and special metals like lithium cobalt oxide for the positive side.

The other important part of a battery is the current collector. Its main purpose is to transfer electrons from the electrode materials to an external circuit and then to the device (example light bulb). The current collector also provides mechanical and conductive supports for the electrode material. Various metals, including aluminum and copper, are commonly used in current collectors.

While LiBs are smaller and lighter than other types of rechargeable batteries, they still have their drawbacks. They can overheat, catch fire, or even explode if they are damaged or if they are charged or stored improperly. They are also not powerful enough to meet the large-scale energy storage demands required for a complete transition away from fossil fuels. Storing energy from wind and solar sources, which are variable and sometimes produce more power than we can use immediately, requires batteries that can hold a lot of energy and release it steadily when needed. One way to make batteries more efficient, safer, and capable of handling the energy storage challenges of renewable energy sources involves using special materials called **nanomaterials**.

NANOMATERIALS

Nanomaterials are super tiny materials, much smaller than we can see, used in technology to make products like batteries work better and do more things.

WHAT ARE NANOMATERIALS AND HOW CAN THEY IMPROVE BATTERIES?

Nanomaterials are new substances that have become increasingly important in recent years. They are special because their basic parts, called **nanoparticles**, are incredibly small, about a billionth of a meter in size. Think of nanoparticles like building blocks that can be arranged in various ways to create nanomaterials. The extremely tiny size of nanoparticles gives nanomaterials unique properties like being able to conduct electricity, react with other substances in interesting ways, or even interact with light and electricity differently than "normal" materials [5]. This makes nanomaterials useful in lots of fields like medicine, electronics, and chemistry.

NANOPARTICLES

The incredibly small building blocks of nanomaterials. Nanoparticles often have special properties due to their tiny size, and can be used to improve products, including batteries and medicines.

One big area in which nanomaterials are making a difference is in LiBs. First, the extremely small size of nanomaterials reduces the distance that lithium ions must travel within the battery. This makes the battery work more efficiently, allowing it to store more energy and charge faster. Nanomaterials also contribute to the battery's durability and safety. Their ability to tolerate changes in structure during the battery's charging and discharging cycles helps prevent the battery from getting damaged over time. This is crucial for maintaining the battery's performance and extending its lifespan. One of the biggest advantages of nanomaterials is their large **surface area** compared to their volume. A large surface area improves the interaction between

SURFACE AREA

The total space on the outside of an object, like measuring all the sides of a box to see how much it can cover.

the battery's electrodes and the electrolyte. As a result, lithium ions move more freely and quickly, enhancing the battery's ability to charge and discharge rapidly.

Nanomaterials are used in various parts of LiBs, including the electrodes and the electrolyte. In the electrodes, nanomaterials help store more lithium ions, which increases the battery's energy storing capacity. When used in the electrolyte, nanomaterials improve the movement of lithium ions, making the battery more efficient. Additionally, coatings made from nanomaterials can be applied to the separators, which can enhance the battery's safety by preventing short circuits and other damage [6].

BUILDING THE BATTERIES OF THE FUTURE

As good as this sound, using nanomaterials in LiBs also comes with some challenges. One problem is that nanomaterials can react in ways we do not want them to, especially because they have a really big surface area for their size. This means they can easily react with other substances, like the electrolyte, inside the battery. These unwanted reactions can create layers of buildup on the nanomaterials that slow down how fast lithium ions can move around, preventing the battery from lasting as long or holding as much power as it should. To fix these issues, scientists are trying to make nanomaterials more stable and they are also experimenting with special additives or protective coatings to stop these unwanted reactions from happening. Also, the way nanomaterials are put together inside the battery needs to be carefully thought out, to make sure batteries work as best as they can. The aim is to figure out both how to use nanomaterials effectively and how to produce them on a large scale.

In conclusion, using nanomaterials allows engineers to adjust the components of LiBs—and other types of electrochemical energy storage devices—on a tiny scale. Nanoparticles might improve battery capacity, charging speed, safety, and lifespan, leading to smaller, more powerful, and longer-lasting LiBs. Researchers must continue to tackle the remaining challenges, because electrochemical energy storage devices are becoming more important every day! Not only will better batteries make our lives easier by powering all our devices, but powerful batteries can also help us store the energy produced from renewable sources. This means that the batteries of the future could help countries transition away from burning fossil fuels. So, you can see that improving batteries not only makes our daily lives easier—it might actually help save the planet!

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SUBMITTED: 04 December 2023; **ACCEPTED:** 20 August 2024; **PUBLISHED ONLINE:** 05 September 2024.

EDITOR: Muthumuni Managa, University of South Africa, South Africa

SCIENCE MENTORS: Yunchao Tang and Javeed Shaikh Mohammed

CITATION: Worku YS, Sikeyi LL, Olalerua SA, Palaniyandy N, Mathe MM and Srinivasu VV (2024) Using Nanomaterials to Make Better Batteries. Front. Young Minds 12:1349295. doi: 10.3389/frym.2024.1349295

CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

SAKINA, AGE: 15
As a junior high school student, I have a keen interest in the field of STEM. I enjoy baking, reading, and watching movies. In the future, I would like to work on both AI and robotics!

ZI-AN, AGE: 9

Hi, I am Zi-An, 9 years old, and coming from a family of teachers. I have inherited a love for knowledge and learning. But my biggest joy? That is definitely my little brother. I absolutely love goofing around and making him laugh! I am fascinated about science. I want to research the secrets of everlasting life, so that people I love will never grow old or die.

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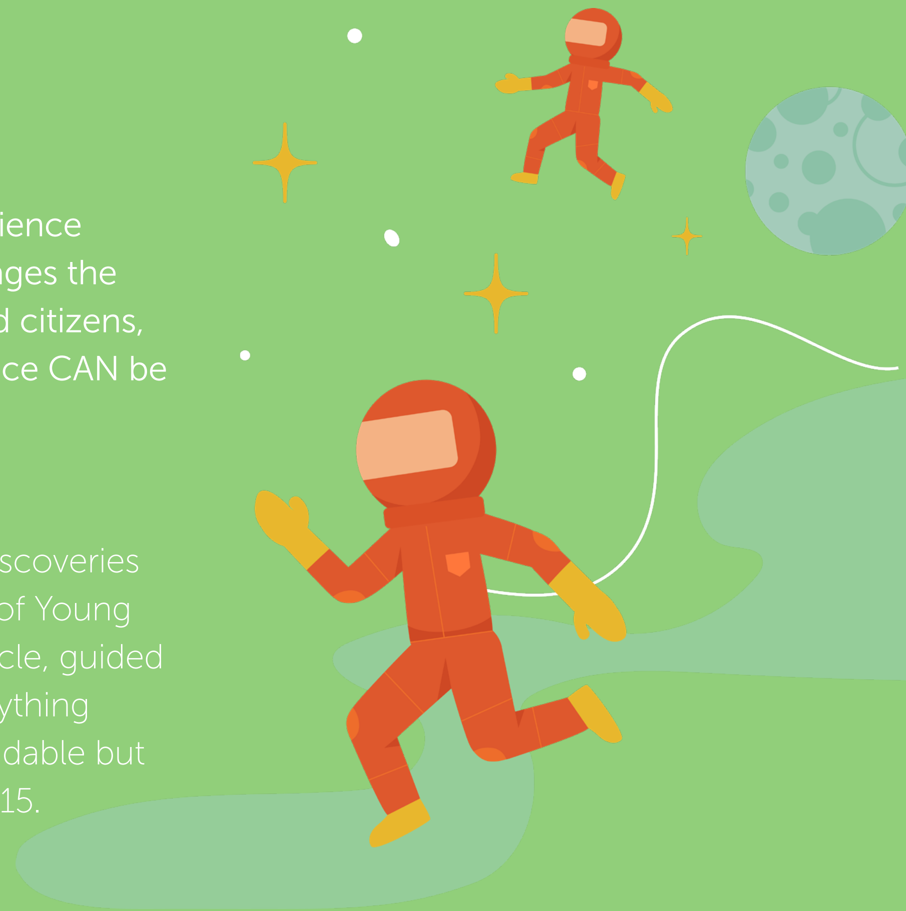

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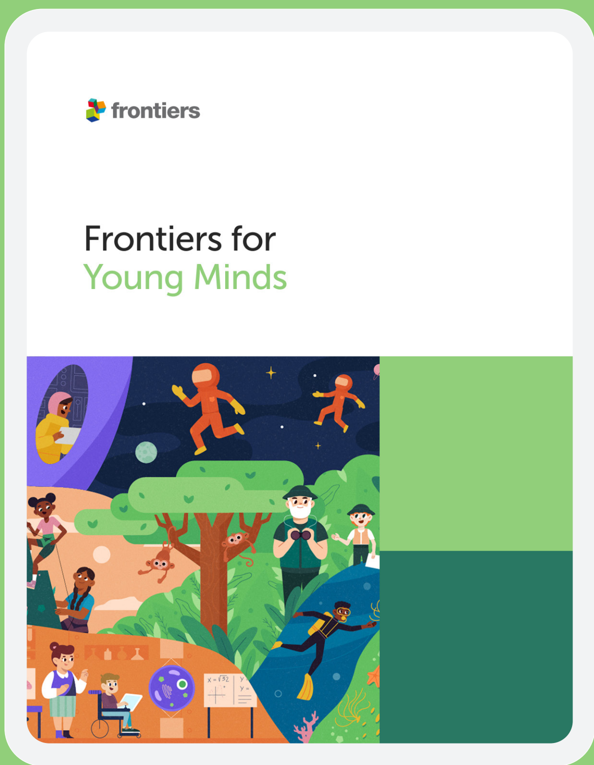

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