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Nanotechnology in Medicine: from Molecules to Targeted Therapy



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BIO-INSPIRED STEM TOPICS FOR ENGAGING YOUNG GENERATIONS
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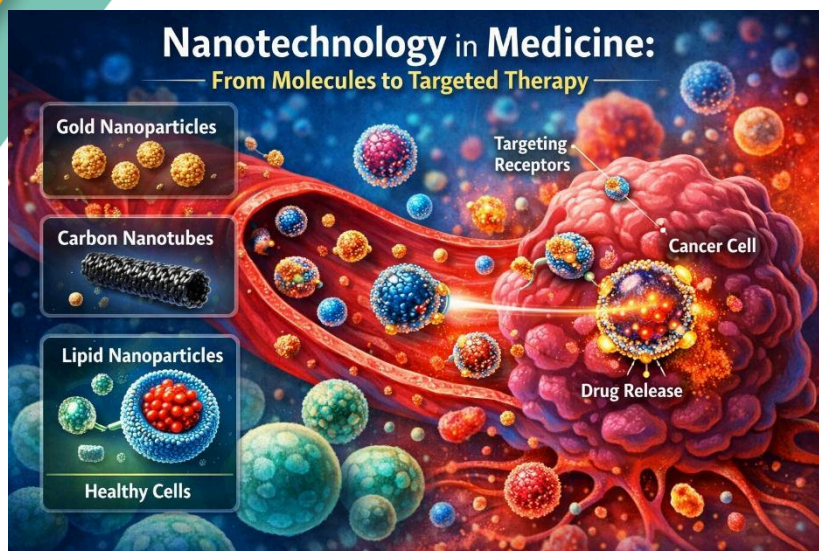
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General topic of the learning path	Interdisciplinary and Emerging Fields
Specific name of the learning unit	Nanotechnology in Medicine: from Molecules to Targeted Therapy
Age of the target users	16-18 years
Requirements for the learner	Students participating in this learning unit should possess basic knowledge of fundamental scientific concepts from physics, chemistry, and biology, particularly the structure of cells, the idea of scale in nature, and simple interactions between matter and energy. No prior knowledge of nanotechnology is required. Learners should be able to work collaboratively in small groups, engage in discussions, and analyze visual or digital materials. Basic digital skills are also recommended, as students will interact with multimedia resources and an Augmented Reality application. Curiosity about scientific innovation and an interest in understanding how modern technologies can improve medical treatments will support meaningful engagement with the activities.
Description of the learning unit	In this learning unit, students will explore the fundamental principles of nanotechnology in medicine through a multidisciplinary approach that integrates physics, chemistry, biology, and medical science. Students will first investigate the nanoscale world and the properties of nanoparticles. They will then analyze how nanoparticles can function as drug carriers and how they interact with biological systems. Finally, they will explore an Augmented Reality simulation that illustrates nanoscale processes involved in drug delivery and targeted cancer therapy.





	Through this learning experience, students will gain a deeper understanding of how modern science translates nanoscale engineering into real medical applications.
Subject: Parties involved	Physics, chemistry, biology, and medical science
Keywords	Nanotechnology Nanomedicine Nanoparticles Targeted Drug Delivery Augmented Reality Learning
Key qualifications, skills and knowledge that can be acquired	Through this learning unit, students develop interdisciplinary knowledge at the intersection of physics, chemistry, biology, and medical science. They gain an understanding of nanoscale dimensions, the unique properties of nanoparticles, and the principles of nanomedicine, particularly targeted drug delivery systems used in modern cancer therapies. Students strengthen scientific reasoning and analytical skills by interpreting visual models, analyzing scientific processes, and discussing real-world biomedical applications. The activities also promote collaborative problem-solving, critical thinking, and communication through group investigations and presentations. In addition, learners acquire digital competencies by interacting with multimedia resources and Augmented Reality simulations. Overall, the unit supports the development of STEM literacy and awareness of emerging technologies shaping future healthcare and biomedical research.
Resources and didactic aids used	The learning unit utilizes a variety of multimedia and interactive resources to engage students and enhance understanding of nanomedicine. Visual aids include diagrams comparing biological structures and nanoscale particles, 3D animations illustrating nanoparticle behavior, and scientific videos explaining drug delivery mechanisms. Worksheets and structured activity sheets guide students through key concepts, ensuring active participation and reflection. Augmented Reality (AR) applications allow immersive visualization of nanoscale processes, enabling learners to manipulate variables and observe drug delivery in real time. Collaborative tools such as shared digital boards and group discussion prompts support teamwork and critical analysis. Additional resources include scholarly articles, scientific databases, and curated online materials that provide up-to-date examples of nanotechnology applications in medicine. These aids collectively





	support a multi-sensory, interactive, and inquiry-based learning approach.
Assessment criteria and evaluation	<p>Students are assessed through a combination of formative and summative methods that evaluate both understanding and application of nanomedicine concepts. Knowledge-based assessment includes quizzes on nanoparticle types, drug delivery stages, and targeted therapy mechanisms. Practical assessment evaluates participation in group activities, accuracy in completing worksheets, and the ability to analyze and present findings. AR-based tasks serve as interactive assessments, where students demonstrate comprehension by manipulating simulations, explaining observed processes, and solving scenario-based challenges. Critical thinking and reflection are assessed through discussions on ethical, safety, and societal implications of nanotechnology in medicine. Evaluation emphasizes both individual understanding and collaborative skills, rewarding accurate conceptual explanations, creativity in problem-solving, and active engagement with digital and AR tools. Feedback is continuous, guiding improvement and reinforcing learning outcomes.</p>





Introduction:

Nanotechnology represents one of the most revolutionary developments in modern science and medicine. By manipulating matter at the nanoscale—typically between 1 and 100 nanometers—scientists can create materials and devices with unique properties that differ significantly from those observed at larger scales. These nanoscale structures can interact with biological systems in highly specific ways, opening new possibilities for diagnosis, treatment, and prevention of diseases.

Medicine has always relied on technological innovation to improve patient outcomes. In recent decades, nanotechnology has become a key tool for developing advanced therapeutic strategies, particularly in areas such as cancer treatment, drug delivery, and biomedical imaging. Nanoparticles can act as carriers that transport drugs directly to diseased cells while minimizing damage to healthy tissues.

Traditional therapies, especially chemotherapy, often have significant side effects because drugs circulate throughout the entire body. Nanotechnology aims to overcome these limitations by enabling targeted drug delivery, where therapeutic molecules are transported to specific cells or tissues.

In this learning unit, students will explore the fundamental principles of nanotechnology in medicine through a multidisciplinary approach that integrates physics, chemistry, biology, and medical science. The unit is organized according to the 3E pedagogical model: Explore, Execute, Enhance.

Students will first investigate the nanoscale world and the properties of nanoparticles. They will then analyze how nanoparticles can function as drug carriers and how they interact with biological systems. Finally, they will explore an Augmented Reality simulation that illustrates nanoscale processes involved in drug delivery and targeted cancer therapy.

Through this learning experience, students will gain a deeper understanding of how modern science translates nanoscale engineering into real medical applications.





Scientific Background: Nanomedicine

What is Nanomedicine?

Nanomedicine is the application of nanotechnology to medical science. It involves the use of nanoscale materials and devices to diagnose, monitor, and treat diseases.

Nanomedicine includes several important areas:

- targeted drug delivery
- medical imaging and diagnostics
- tissue engineering
- regenerative medicine
- nanoscale biosensors

Because nanoparticles are extremely small, they can interact directly with biological molecules such as proteins, DNA, and cell membranes.

Why Size Matters

The nanoscale dimension is critical because it corresponds to the scale of biological structures.

For example:

Structure	Approximate Size
Human hair	80,000–100,000 nm
Red blood cell	7,000 nm
Virus	100 nm
Protein	10 nm
Nanoparticle	1–100 nm

Nanoparticles are therefore small enough to circulate through blood vessels and interact with individual cells.

At the nanoscale, materials exhibit unique properties due to:

- large surface-to-volume ratio
- increased chemical reactivity
- quantum effects
- enhanced optical properties

These properties allow nanoparticles to perform functions that are impossible for larger particles.

Types of Nanoparticles Used in Medicine

Several types of nanoparticles are commonly used in nanomedicine.

Gold Nanoparticles

Gold nanoparticles have special optical properties and are widely used for:





- medical imaging
- cancer detection

- photothermal therapy

They can absorb light and convert it into heat, which can be used to destroy tumor cells.

Carbon Nanotubes

Carbon nanotubes are cylindrical carbon structures with remarkable strength and conductivity.

Applications include:

- drug transport
- biosensors
- tissue engineering

Their hollow structure allows them to carry molecules through biological environments.

Liposomes

Liposomes are spherical vesicles composed of lipid bilayers similar to biological membranes.

They are particularly useful for:

- drug encapsulation
- controlled drug release
- targeted therapy

Liposomes can protect drugs from degradation while transporting them through the bloodstream.

Section 1: Explore

Discovering the Nanoscale World

The Explore phase is designed to stimulate students' curiosity and activate their prior knowledge about matter, scale, and medical technology. At the beginning of the lesson, the teacher introduces the topic by asking a simple but powerful question:

“How small can technology become, and what happens when we reach the size of biological molecules?”

Students are encouraged to reflect on how modern science increasingly works at extremely small scales and how this can influence medicine. To facilitate





engagement, the teacher presents a series of images and short animations illustrating nanoscale phenomena and biological structures.

The goal of this phase is not yet to provide formal explanations, but rather to encourage students to observe, question, and hypothesize.

Engagement Video

The lesson begins with short videos that introduce the idea that nanoscale technology can revolutionize medicine.

<https://www.youtube.com/watch?v=emEua2eJp1U&t=3s>

Nanoparticle Drug Delivery in Cancer Therapy (3D Scientific Animation)

This video helps students visualize how physical processes and biological systems interact at microscopic and nanoscopic scales. Understanding these interactions is essential for comprehending how nanoparticles behave inside the human body. Research shows that nanotechnology enables new strategies for transporting drugs directly to diseased tissues while minimizing damage to healthy cells.

Brainstorming Activity: Science in Everyday Life

Students are divided into small groups and asked to identify examples of scientific technologies that interact with biological systems. Examples might include:

- vaccines
- medical imaging techniques
- diagnostic tests
- wearable biosensors

Groups write their ideas on a shared board and briefly explain how technology helps diagnose or treat diseases. The teacher then introduces the concept that nanotechnology represents the next frontier in this technological evolution.

Activity: Visualizing the Nanoscale

One of the biggest conceptual difficulties for students is understanding how small the nanoscale actually is. To address this challenge, the teacher presents a visual comparison between different biological and physical structures.

Students examine diagrams comparing:

- human hair





- cells
- viruses
- nanoparticles

Discussion questions:

Students are then asked to answer guiding questions:

- Why is the nanoscale similar to the scale of biological structures?
- Why might nanoparticles interact more easily with cells than larger particles?
- Why are nanoparticles suitable for medical applications?
- How might nanoparticles travel through blood vessels?

This discussion helps students recognize that **the nanoscale corresponds closely to the scale of biological processes**, which explains why nanotechnology is so promising in medicine.

Activity: Everyday Nanotechnology

Students work in groups to research examples of nanotechnology used in medicine, such as:

- nanoparticle-based cancer therapy
- lipid nanoparticles used in vaccines
- nanosensors for disease detection
- nanomaterials in regenerative medicine

Students summarize their findings in a short presentation. The objective is to highlight that nanomedicine is a highly interdisciplinary field combining physics, chemistry, biology, and engineering.

Ethical and Safety Issues in Nanomedicine

While nanotechnology offers many benefits, it also raises important ethical and safety questions. The Explore phase concludes with a classroom discussion about ethical implications of emerging medical technologies.

Students examine potential concerns such as:

- nanoparticle toxicity
- long-term accumulation in organs





- environmental impact
- unequal access to advanced treatments

Because nanoparticles are extremely small, they may interact with biological systems in unexpected ways.

Possible concerns include:

- toxicity
- accumulation in organs
- environmental impact

Scientists must carefully test nanoparticles to ensure they are safe for medical use.

Ethical Considerations

Several ethical questions arise when developing nanomedicine technologies.

Patient Safety

New treatments must undergo rigorous clinical trials before being used in patients.

Accessibility and Equity

Advanced medical technologies may be expensive, raising concerns about equal access to healthcare.

Privacy and Data Protection

Nanotechnology may enable advanced biosensors capable of monitoring biological signals. This raises questions about the privacy of medical data.

Responsible Innovation

Researchers must balance innovation with ethical responsibility, ensuring that technologies benefit society while minimizing risks.





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Section 2: Execute

Nanoparticle Drug Delivery Systems

In the Execute phase, students move from exploration to a deeper analysis of the scientific mechanisms underlying nanomedicine. The focus is on understanding how nanoparticles can function as drug delivery systems capable of transporting therapeutic molecules to specific locations in the body.

Traditional medical treatments often rely on drugs that circulate throughout the entire bloodstream. While effective in treating disease, this approach frequently produces severe side effects because healthy tissues are also exposed to the drug.

Nanotechnology offers a solution to this problem through targeted drug delivery. Nanoparticles can be engineered to transport drugs selectively to diseased tissues, increasing treatment efficiency while reducing toxicity.

The Drug Delivery Process

Students examine the three main stages involved in nanoparticle drug delivery.

Stage 1 – Nanoparticle Design

Scientists design nanoparticles with specific properties that determine their behavior inside the body. Important parameters include:

- particle size
- shape
- surface chemistry
- electrical charge

These characteristics influence how nanoparticles circulate in blood, interact with cells, and reach target tissues.

Stage 2 – Drug Loading

Once the nanoparticle structure is created, it is loaded with therapeutic molecules.

For example:

- Liposomes encapsulate drugs inside a lipid bilayer similar to biological membranes.
- Polymeric nanoparticles bind drug molecules to their surface.
- Carbon nanotubes can carry molecules through their hollow cylindrical structure.





This stage ensures that the drug remains stable while traveling through the body.

Stage 3 – Controlled Drug Release

After reaching the target tissue, the nanoparticle releases the drug.

Drug release can be triggered by environmental factors such as:

- pH changes in tumor environments
- specific enzymes
- temperature differences
- external stimuli such as light or magnetic fields

Controlled release allows the drug to act exactly where it is needed.

Targeted Cancer Therapy

Cancer cells often present specific proteins on their surface called receptors. Scientists design nanoparticles with molecules known as ligands that bind selectively to these receptors.

This interaction follows the lock-and-key model, a concept commonly used in molecular biology.

When the nanoparticle encounters a cancer cell:

1. The ligand binds to the receptor.
2. The nanoparticle attaches to the cell membrane.
3. The cell internalizes the nanoparticle.
4. The drug is released inside the tumor cell.

Because healthy cells lack these receptors, they interact much less with the nanoparticles. As a result, targeted nanotherapy can significantly reduce damage to healthy tissues.

Student Activities

Students work through structured worksheets that reinforce key concepts.

Activities include:

- ordering biological structures by size
- matching nanoparticle types with their applications
- describing the steps of drug delivery
- explaining the receptor–ligand interaction mechanism

These exercises help students translate abstract scientific ideas into concrete understanding.

Activity Sheets for Students

Activity Sheet 1 – Understanding Scale

1. Arrange the following structures from largest to smallest:
 - virus
 - human hair





- nanoparticle
- red blood cell

2. Why is nanoscale size useful for medical applications?

Activity Sheet 2 – Nanoparticle Types

Match each nanoparticle type with its function:

Nanoparticle Function

Gold nanoparticles

Carbon nanotubes

Liposomes

Activity Sheet 3 – Drug Delivery Process

Describe the three steps of nanoparticle drug delivery.

- 1.
- 2.
- 3.

Explain why targeted drug delivery reduces side effects.

Activity Sheet 4 – Cancer Targeting

Explain how nanoparticles recognize cancer cells.

Use the lock-and-key model to describe the interaction.

Activity Sheet 5 – Reflection Questions

1. What advantages does nanotechnology offer in medicine?
2. What potential risks must scientists consider?





Section 3: Enhance

Augmented Reality for Deeper Understanding

The Enhance phase integrates Augmented Reality technologies to expand students' understanding beyond what can be observed through traditional experiments. Augmented Reality allows students to visualize nanoscale processes that cannot be observed directly.

In the AR exercise “*Nanotechnology in Medicine: From Molecules to Targeted Therapy*”, students interact with a sequence of scenes illustrating nanoparticle behavior.

AR Scene 1 – Introduction

Students scan an AR marker using a tablet or smartphone.

A three-dimensional animation introduces the concept of nanomedicine and illustrates how nanoparticles move through the bloodstream.

AR Scene 2 – Scale Comparison

Students observe an interactive visualization comparing:

- human hair
- red blood cells
- viruses
- nanoparticles

This scene reinforces the concept of relative scale, helping students better understand how nanoparticles interact with biological systems.

AR Scene 3 – Types of Nanoparticles

Students explore 3D models of three commonly used nanoparticle types:

- gold nanoparticles
- carbon nanotubes
- liposomes

Each structure can be rotated and examined from different angles.

A short quiz asks students:

Which nanoparticle type encapsulates drugs inside a lipid membrane?

Correct answer: liposomes

AR Scene 4 – Drug Delivery Mechanism

Students observe the complete drug delivery process:

1. empty nanoparticle
2. drug-loaded nanoparticle





3. nanoparticle reaching target tissue
4. drug release

Interactive elements allow students to trigger each step.

A quiz question reinforces the concept:

What is the main advantage of nanoparticle drug delivery?

Correct answer: targeted therapy with reduced side effects

AR Scene 5 – Targeting Cancer Cells

Students observe nanoparticles binding to receptors on tumor cells.

This visualization illustrates the receptor–ligand recognition mechanism and shows how nanoparticles enter cancer cells.

Quiz question:

How do nanoparticles recognize cancer cells?

Correct answer: specific receptor–ligand interaction

AR Scene 6 – Final Assessment

The AR activity concludes with a short interactive quiz reviewing the key concepts learned during the unit.

Students reflect on questions such as:

- How does nanotechnology improve medical treatments?
- Why is nanoscale engineering important for modern medicine?
- What challenges remain in developing safe nanomedical technologies?

Learning Impact

Augmented Reality enhances learning by:

- making invisible processes visible
- improving conceptual understanding
- increasing student engagement
- connecting theoretical knowledge with real-world applications

Through this immersive experience, students gain a deeper appreciation of how nanoscale science is transforming healthcare.

Conclusion:

Nanotechnology is transforming modern medicine by enabling new approaches to diagnosis and treatment.

In this learning unit, students explored nanoscale structures, nanoparticle types, and drug delivery mechanisms. They learned how nanoparticles can transport drugs directly to diseased cells and reduce harmful side effects.





The integration of Augmented Reality provided an immersive experience that allowed students to visualize nanoscale processes and understand how nanoparticles interact with biological systems.

Nanomedicine represents a powerful example of interdisciplinary science, combining physics, chemistry, biology, and engineering to address real-world medical challenges.

Understanding these principles prepares students for future studies and careers in emerging scientific fields such as biomedical engineering, pharmaceutical science, and nanotechnology.

Phase	Description
Explore	- Research and Discovery: Students investigate examples of nanotechnology in everyday life and medicine, such as nanoparticle-based vaccines, diagnostic biosensors, and drug delivery systems. Through guided internet research and classroom discussion, they explore how nanoscale materials interact with biological systems and why size matters in medical applications.
	- Content Development: Teachers introduce the concept of the nanoscale and nanomedicine through visual comparisons (human hair, red blood cells, viruses, nanoparticles) and short scientific videos explaining nanoparticle drug delivery and nanotechnology in healthcare. Diagrams, animations, and conceptual models help students visualize structures that cannot be directly observed..
	- Needs Analysis: Teachers assess students' prior knowledge about scale, cells, and basic biomedical technologies. Students share their initial ideas about how medicines travel inside the body and discuss possible misconceptions about nanotechnology, such as confusion between micro- and nanoscale dimensions.
Execute	- Curriculum Implementation: Students study how nanoparticles are designed and used in targeted drug delivery systems. Through guided activities and worksheets, they analyze the structure and function of different nanoparticle types (gold nanoparticles, carbon nanotubes, liposomes) and explore how drugs can be loaded and released at specific target sites..
	- Interactive Exercises: Students work in groups to complete structured learning activities, including ordering biological structures by size, matching nanoparticle types with their functions, and describing the stages of nanoparticle drug delivery. Groups collaboratively analyze case studies of nanoparticle-based cancer therapies.
	- Feedback Collection: Students present their findings to the class and discuss the advantages and limitations of nanomedicine. Teachers guide reflection on how targeted therapies can reduce side effects compared to traditional treatments. Peer discussion helps clarify misunderstandings and reinforce key concepts.
Enhance	- AR Integration: Students use an Augmented Reality (AR) application to visualize nanoscale structures and processes involved in nanomedicine. The AR experience includes scenes showing nanoscale size comparisons, types of nanoparticles, and the mechanism of targeted drug delivery inside the body..
	- Interactive Learning: Through AR simulations, students observe how nanoparticles move through blood vessels, bind to specific receptors on cancer cells, and release drugs into target





tissues. They can manipulate variables such as nanoparticle type or drug release mechanism and observe the resulting changes.

Gamified Content:

- **Points and Badges:** Students earn points and digital badges for correctly answering AR quiz questions, identifying nanoparticle types, and completing learning activities related to nanomedicine.

- **Quests and Levels:** Groups complete progressive AR challenges, such as identifying nanoscale structures, explaining drug delivery stages, and solving case-based scenarios related to cancer therapy.

- **Rewards for Exploration:** Additional points are awarded when students identify new real-world applications of nanotechnology in medicine or propose innovative ideas for future nanomedical technologies.

- **Collaborative Gamified Tasks:** Teams work together to solve AR-based missions, such as designing an effective nanoparticle drug delivery system or selecting the most appropriate nanoparticle type for a specific medical problem.

AR-Based Assessments: Students demonstrate their understanding by completing AR-guided tasks and producing short reports explaining how nanoparticles interact with biological systems and how targeted therapies work.

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