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Modelling the impact of GMOs

BIOS4YOU AR 2.0

BIO-INSPIRED STEM TOPICS FOR ENGAGING YOUNG GENERATIONS
THANKS TO THE USE OF AUGMENTED REALITY

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Source: https://www.freepik.com/free-vector/genetically-modified-organisms-isometric-flowchart_6169690.htm

General topic of the learning path	Bio-Technology. Biomanufacturing and Synthetic Biology
Specific name of the learning unit	Modelling the impact of GMOs
Age of the target users	14-18 years
Requirements for the learner	Basic knowledge of Science Access to AR-compatible devices (smartphones, tablets, or AR glasses)
Description of the learning unit	This learning unit and activity introduces students to the impact of genetically modified organisms (GMOs) on the environment, agriculture, and society. Using augmented reality (AR) technologies, students will model different scenarios of GMO application, analyze potential benefits and risks, and discuss ethical, economic, and ecological aspects. The learning unit combines inquiry-based learning, collaborative activities, and reflection to support critical understanding of biotechnology and its real-world applications.
Subject: Parties involved	Biology, Biotechnology, Environmental Science, STEM Education, Digital Technologies
Keywords	GMO, genetic modification, augmented reality, agriculture, ecosystems, biodiversity, ethics, food safety, biotechnology

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Key qualifications, skills, and knowledge that can be acquired	• Understanding what GMOs are and how they are produced Ability to analyze the impact of GMOs on ecosystems and human health Critical thinking and argumentation when evaluating benefits and risks of biotechnology • Digital competence through the use of AR technologies • Teamwork and communication skills • Problem-solving skills through scenario modelling
Resources and didactic aids used	• AR applications or platforms • Mobile devices (tablets, smartphones, AR glasses) • Online resources and educational videos • Worksheets and task cards • Projector or interactive whiteboard • Teacher-prepared presentations
Assessment criteria and evaluation	Assessment is based on both formative and summative approaches. • **Formative assessment:** ○ Participation in AR-based exploration and discussions ○ Engagement during scenario analysis and group work ○ Reflection on benefits, risks, and ethical aspects of GMOs • **Summative assessment:** ○ Performance in the AR-based test (Phase 1 of the exercise) ○ Quality and relevance of student-created AR scenarios and questions (Phase 2) ○ Ability to explain cause–effect relationships and justify conclusions

Introduction

Genetically Modified Organisms (GMOs) are widely used in agriculture, biotechnology, and medicine, yet their impact on the environment, food systems, and society is often complex and difficult to visualize. This learning unit introduces GMOs through modelling and simulation-based approaches that help students explore how genetic modifications can influence organisms and ecosystems. By using digital modelling tools and Augmented Reality (AR), learners can analyze potential benefits and risks of GMOs, understand cause–effect relationships, and develop a more informed perspective on how biotechnology shapes real-world challenges.

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Explore

1. Understanding GMOs and Their Impact

In this section, students develop a foundational understanding of genetically modified organisms (GMOs), how they are created, and why their impact can be complex. The Explore phase introduces key biological and biotechnological concepts needed to understand genetic modification before engaging in modelling, AR-based analysis, and creative activities later in the unit.

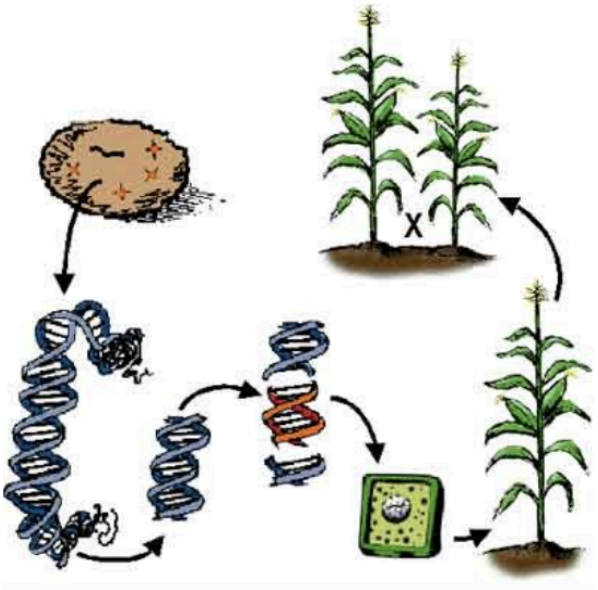

Figure 1. The Process of Plant Genetic Engineering. Source: https://passel2.unl.edu/view/lesson/7f79e74ec2cd/8

1.1 What Are Genetically Modified Organisms (GMOs)?

A genetically modified organism (GMO) is an organism whose genetic material has been deliberately altered using genetic engineering techniques. Unlike traditional breeding, which selects traits over many generations, genetic modification allows scientists to introduce specific genes directly into an organism's genome. (https://en.wikipedia.org/wiki/Genetically_modified_organism)

Example: Bt maize, engineered with a bacterial gene (Bacillus thuringiensis) for pest resistance. (https://en.wikipedia.org/wiki/Genetically_modified_organism)

GMOs can be plants, animals, or microorganisms. They are commonly used in agriculture to improve crop resistance, productivity, or nutritional value, and in biotechnology and medicine for research and production purposes.

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Watch the video:

To support students' understanding of genetically modified organisms, learners are encouraged to watch a short introductory video explaining what GMOs are and how they are created. The video provides a clear, accessible overview of genetic modification processes and real-life examples, helping students build a common foundation before analysing GMO impacts through modelling and Augmented Reality activities.

Video: *What Are Genetically Modified Organisms (GMOs)?*
https://www.youtube.com/watch?v=jYjvJyEMHZ4

1.2 How Genetic Modification Works (Basic Principles)

Genetic modification involves identifying a gene with a desired trait and inserting it into another organism. This process typically includes:

- Isolating a specific gene from one organism (e.g., Bt toxin gene from bacteria).
- Inserting the gene into a vector (often a plasmid).
- Transferring the gene into the target organism (e.g., via Agrobacterium or gene gun).
- Ensuring the new gene is expressed correctly.

This allows organisms to gain new characteristics, such as resistance to pests, tolerance to herbicides, or the ability to produce useful substances like insulin.

1.3 Examples of GMOs in Real Life

GMOs are widely present in modern biotechnology and agriculture. Common examples include:

- **Genetically modified crops**, such as maize or soybeans, designed to resist pests or tolerate environmental stress. Bt maize or Roundup Ready soybeans, designed to resist pests or tolerate herbicides (MON810, approved 1990s). (https://en.wikipedia.org/wiki/Genetically_modified_maize)
- **GMO microorganisms**, used to produce medicines like insulin or vaccines. Example: E. coli engineered to produce human insulin (Humulin, FDA-approved 1982)
- **Research organisms**, modified to study gene function and disease mechanisms.

These examples show that GMOs are not limited to food production but play a broader role in science and medicine.

1.4 Potential Benefits of GMOs

Genetic modification offers several potential benefits, supported by rigorous meta-analyses:

- Increased crop yields (e.g., +22% for GM maize according to meta-analyses conducted 2014–2021. Source: https://pmc.ncbi.nlm.nih.gov/articles/PMC4218791/).
- Reduced pesticide use (-37% for herbicide-tolerant crops, 2014 meta-analysis).

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- Improved nutritional content (e.g., Golden Rice with beta-carotene for vitamin A deficiency. Source: https://pmc.ncbi.nlm.nih.gov/articles/PMC4218791/).
- Enhanced resistance to environmental challenges (drought, salinity, soil stress). (Source: https://en.wikipedia.org/wiki/Genetically_modified_food).

These benefits address global challenges such as food security, reducing chemical inputs in agriculture, and building resilience to climate variability. (More: https://www.who.int/news-room/questions-and-answers/item/food-genetically-modified).

1.5 Potential Risks and Concerns

GMOs also raise valid concerns requiring careful evaluation, supported by ongoing ecological and social research:

- Effects on biodiversity (e.g., gene flow to wild relatives, herbicide-resistant "superweeds" documented since 2000s; non-target insect impacts under investigation) (source: https://www.science.org/doi/10.1126/science.ado9340).
- Potential gene transfer to non-target organisms (horizontal gene transfer; rare but documented in laboratory conditions).
- Long-term environmental impacts (soil microbial communities, effects on non-target insects such as monarch butterflies—debated since 1999 study, reassessed 2010–2020) (source: https://ecoservantsproject.org/genetically-modified-organisms-gmos-and-the-environment-impacts-benefits-and-concerns/).
- Ethical, social, and economic considerations:
    - Farmer dependency on proprietary seeds and licensing agreements.
    - Labeling regulations and consumer acceptance (varies by region).
    - Equitable access to GM technologies in developing countries.
    - Patent ownership and intellectual property concerns.

Understanding GMOs therefore requires systems thinking, where biological, environmental, and societal factors are considered together rather than in isolation.

Watch the video

To encourage critical thinking and discussion, students are invited to watch a short video presenting different perspectives on genetically modified organisms. The video highlights why the impact of GMOs can be complex and context-dependent, supporting informed analysis rather than simple “for or against” positions. This resource prepares learners for AR-based scenario analysis and decision-making activities in the following phases.

Video: *Genetically Modified Organisms (GMOs) – Different Perspectives*
https://www.youtube.com/watch?v=-RW5aRphVFw

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1.6 Why Modelling and AR Are Useful for Understanding GMOs

The effects of genetic modification are often invisible and occur over time, making them difficult to understand through static images or text alone. Modelling and Augmented Reality (AR) help visualize processes such as gene insertion, trait expression, and potential environmental interactions.

By exploring GMO-related scenarios through AR-based tests and interactive models, students can better understand cause–effect relationships and evaluate different outcomes. This prepares learners to engage critically with the exercise activities and to reflect on how biotechnology decisions influence real-world systems.

Example: AR slider shows GMO maize yield vs. pesticide use changes. Students simulate scenarios, evaluate outcomes, and develop critical thinking for exercise activities. (https://bios4you.infoproject.eu/how-delightex-ar-is-transforming-stem-education-classroom-practices-and-teaching-tips/)

Visual summary: Benefits and risks of GMOs

The following visual summary presents commonly discussed potential benefits and risks of genetically modified organisms. It is used as a discussion and analysis tool to support systems thinking rather than to promote a specific viewpoint. Students are encouraged to compare points, identify trade-offs, and consider how different contexts (environmental, economic, and social) influence the evaluation of GMO use.

✓ Benefits of GMOs	Risks of GMOs ✗
Nutritional value of foods could be improved (e.g. by introducing proteins, vitamins or vaccines)	New traits could cause adverse health reactions (e.g. new proteins may cause allergic responses)
Crops can be produced that lack known allergens	Removal of traits could have unknown effects
Crops can grow in arid conditions for better yield (e.g. by introducing drought resistant genes)	Crops may limit biodiversity of local environment (increased competition with native species)
GM crops can produce herbicides to kill pests	Cross pollination could lead to 'super weeds'
Improve food supply / agriculture in poor countries (GM crops can be engineered for improved yields)	Patents restrict farmers from accessing GM seeds (biotech companies hold monopolies over crop use)
GM crops may have longer shelf lives (less spoil)	Foods with GM components may not be labeled
Reduces economic costs and carbon footprint – less need for land clearing and pesticide usage	Different governments may have conflicting regulatory standards concerning safe usage

(Sourse: https://old-ib.bioninja.com.au/standard-level/topic-3-genetics/35-genetic-modification-and/gmo-debate.html)

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1.7 Questions for Reflection

- How do GMOs differ from organisms created through traditional breeding?
- Which benefits of GMOs seem most significant, and why?
- What potential risks require further investigation?
- Why is it important to consider environmental and societal impacts together?
- How might modelling and AR help explain complex biotechnology topics?

Execute

2. Modelling and Analysing the Impact of GMOs Through Bio-Inspired Design

In the **Execute** phase, students apply their understanding of genetically modified organisms by exploring how natural biological processes inspire practical solutions for real-world challenges. Genetic modification itself is based on observing and using mechanisms that already exist in nature, such as gene expression, adaptation, and inheritance. In this phase, learners examine how these natural abilities are used in biotechnology to design organisms with specific traits and how such designs may influence ecosystems and human environments.

2.1 Bio-Inspiration: Learning from Natural Genetic Processes

Nature continuously adapts through genetic variation and selection. Genetic engineering builds on these natural principles by introducing targeted changes to an organism's genome. Students analyse how modifying a single gene can result in visible traits, such as pest resistance or improved tolerance to environmental stress.

This bio-inspired approach helps learners understand that GMOs are not created randomly, but are designed based on biological knowledge. Students focus on the relationship between **genetic change → organism trait → environmental impact**, which is essential for evaluating both benefits and risks of biotechnology.

2.2 Using AR to Achieve the Learning Objectives

Augmented Reality (AR) plays a key role in supporting the main objective of this learning unit: understanding the impact of GMOs through modelling and analysis rather than memorisation. AR applications allow students to visualise genetic modification processes and their consequences in a clear and interactive way.

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In this unit, AR supports learning by enabling students to:

- explore **cause–effect relationships** between genetic changes and organism traits,
- visualise **invisible processes**, such as gene insertion and expression,
- interact with **scenario-based environments** showing potential impacts on agriculture and ecosystems.

Useful AR features for this phase include:

- interactive AR scenarios with embedded questions,
- visual layers that show changes before and after genetic modification,
- immediate feedback and scoring in AR-based tests,
- simple AR creation tools (e.g. Delightex) for student-designed scenarios.

These features transform AR into a thinking and modelling tool rather than a passive visual aid.

2.3 Practical Exercises and Global Learning Examples

In this phase, students engage in practical, hands-on activities inspired by bio-inspired learning approaches used worldwide in STEM and biotechnology education. Similar AR-based modelling activities are commonly applied to help learners understand complex systems and evaluate technological impacts.

Examples of practical activities include:

- analysing an AR-based test that models GMO scenarios and their outcomes,
- comparing different genetic modification strategies and their potential effects,
- creating simple AR scenes that represent GMO-related situations,
  designing and testing questions that assess understanding of environmental and societal impact.

Such activities reflect real scientific and educational practices, where modelling, simulation, and digital visualisation are used to explore complex biological systems. By actively engaging with AR scenarios and creating their own content, students move from understanding concepts to applying and evaluating them in meaningful contexts.

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Enhance

3. Strengthening Understanding of GMO Impacts Through AR

In the **Enhance** phase, Augmented Reality (AR) is used to deepen students' understanding of genetically modified organisms by transforming abstract and complex processes into interactive learning experiences. GMO-related changes often occur at the genetic level and influence systems over time, making them difficult to grasp through traditional teaching methods alone. AR provides a powerful way to visualise these processes and explore their broader implications.

3.1 Deepening Conceptual Understanding Through AR

AR allows students to explore genetic modification as a dynamic process rather than a static concept. By interacting with AR scenarios, learners can observe how genetic changes lead to specific organism traits and how these traits may affect agricultural systems and ecosystems.

Through AR-based visualisation, students can:

- examine genetic changes step by step,
- observe differences between modified and non-modified organisms,
- explore multiple possible outcomes resulting from a single genetic modification.

This interactive approach supports deeper conceptual understanding and helps students connect biological mechanisms with real-world consequences.

3.2 Making Complex Systems More Accessible

The impact of GMOs often involves interconnected systems, such as food chains, ecosystems, and human activities. AR supports systems thinking by allowing students to visualise these relationships in an integrated way.

By interacting with layered AR content, learners can:

- identify cause–effect relationships,
- understand how changes in one part of a system influence others,
- explore trade-offs between benefits and risks.

This makes AR particularly suitable for addressing the complexity of biotechnology topics, where simple answers are rarely sufficient.

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3.3 Increasing Engagement and Active Participation

AR encourages students to take an active role in their learning. Instead of passively receiving information, learners interact with scenarios, answer questions, and test their own understanding. When students create their own AR-based questions or scenarios, engagement increases further, as they take ownership of both content and assessment.

Collaborative use of AR also supports discussion and peer learning. Students compare interpretations, justify their choices, and reflect on different perspectives related to GMO use and regulation.

3.4 Practical Integration of AR Tools

In this learning unit, AR tools such as **Delightex** are used to support exploration, assessment, and creation. Practical ways to integrate AR include:

- using AR-based tests with scoring to assess initial understanding,
- embedding explanatory text and questions directly into AR scenes,
- allowing students to design simple AR scenarios that model GMO impacts,
- using AR projects as discussion starters and reflective tools.

These practices align with how AR is increasingly used in STEM education worldwide to support inquiry, modelling, and evidence-based discussion.

3.5 Encouraging Reflection and Further Exploration

The Enhance phase supports reflection by encouraging students to evaluate both the technology and the topic itself. Learners reflect on how AR influenced their understanding of GMOs and how digital modelling can support informed decision-making in science and society.

By linking biological knowledge, AR technology, and real-world challenges, this phase encourages students to continue exploring biotechnology topics beyond the learning unit and to engage critically with emerging scientific innovations.

Conclusion

This learning unit explored genetically modified organisms by combining biological knowledge with modelling and Augmented Reality. Through the Explore, Execute, and Enhance phases, students analysed how genetic modifications influence organisms, ecosystems, and society, while applying bio-inspired and systems thinking. The use of AR tools supported visualisation of complex processes, encouraged critical evaluation of benefits and risks, and strengthened students' understanding of biotechnology as a key driver of real-world solutions, inspiring further inquiry into genetic engineering and its impact.

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Phase	Description
Explore	- Research and Discovery: Students explore what genetically modified organisms are, how genetic modification works, and why GMOs can have complex impacts on organisms, ecosystems, and society.
	- Content Development: Learners build foundational knowledge through texts, diagrams, and visual examples, analysing benefits, risks, and ethical considerations related to GMOs.
	- Needs Analysis: Students identify challenges in understanding invisible genetic processes and long-term environmental effects, recognising the need for modelling and AR-based visualisation tools.
Execute	- Curriculum Implementation: Students apply biological knowledge by analysing bio-inspired genetic processes and modelling GMO impacts through interactive AR-based activities.
	- Interactive Exercises: Learners complete an AR-based test with scoring to assess their understanding, then design simple AR scenarios and questions related to GMO topics using Delightex.
	- Feedback Collection: Students receive automatic feedback through the AR test and peer/teacher feedback during discussion and AR project creation.
Enhance	- AR Integration: Students use AR tools to visualise genetic modification processes, compare outcomes, and explore interconnected systems such as agriculture and ecosystems.
	- Interactive Learning: Learners interact with AR scenarios, reflect on results, and discuss different perspectives on GMO use and impact.
	Gamified Content: • **Points and Scores:** Awarded automatically during the AR-based test. • **Badges:** For completing AR creation tasks and designing meaningful questions. • **Challenges:** Students compare scenarios and evaluate trade-offs between benefits and risks.
	AR-Based Assessments: Understanding is demonstrated through test performance, quality of student-created questions, and reflective discussion supported by AR visualisation.

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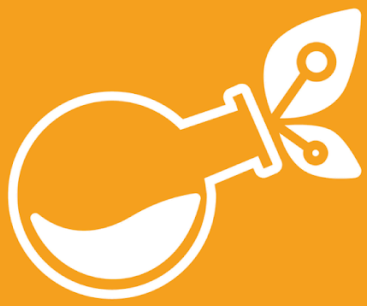

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