EDUCATIONAL GAMES FOR BIOECONOMY LEARNING: INSIGHTS FROM THE HORIZON EUROPE GENB PROJECT

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Abstract

The Horizon Europe GenB [1] project has launched a series of educational games focused on bioeconomy, aimed at engaging young people across various age groups. The games — *BioHeroes: Let's Save the Planet!*, *The Bio Race*, *Green Chat Quartet*, and *Escape4Future- Chemistry Meets Circular Bioeconomy* — merge entertainment with learning about sustainability and bioeconomy. These games are part of the GenB educational Toolkit [2], a curated set of resources designed to enhance bioeconomy learning and offer educators accessible science education tools.

The collection uses a game-based learning (GBL) approach to boost student engagement and motivation while facilitating understanding of complex topics [3]. This approach also helps students to develop 21st-century skills like collaboration, problem-solving, creativity, and strategic thinking. Games in education not only improve academic performance but also foster an interactive and cooperative learning environment, preparing young people to address real-world challenges [4].

The games were developed through a human-centred design (HCD) approach, with active involvement of more than 740 participants (students, teachers and parents) during a series of co-creation and validation workshops. This participative approach with students across primary and secondary schools, along with their teachers in three European countries —Italy, the Netherlands, and Spain—partners of the GenB Project—has improved the games' relevance, usability, and impact. Additionally, rounds of validation by experts from fields such as education, bioeconomy, gaming, and design have ensured that the games are technically sound and pedagogically effective. This iterative process enabled adjustments to align the games with users' educational needs and preferences.

Each game targets a specific age group and can be played by children and their teachers, parents, or other educational stakeholders, to take the opportunity to deepen concepts and complement the gamified experience with educational activities. Addressing various aspects of the bioeconomy, as well as sustainability concepts connected to it—such as climate change, green chemistry, bioeconomy professions, and bio-based products—the games offer engaging ways to explore these themes. They come in different formats (e.g., board game, card game, escape game), providing flexible, free downloadable options in three of the four games, which can be adapted to various educational settings, enabling young people to interact with bioeconomy concepts across diverse contexts.

The GenB initiative empowers "Generation Bioeconomy" by fostering environmental awareness, sustainability, and circularity, encouraging young people to lead sustainable lifestyle changes. This paper outlines the development and impact of the games created by GenB, showcasing innovative ways in which learning through and by making games can help new generations build knowledge on scientific topics and navigate the challenges of a sustainable future.

Keywords: Gamification, human-centred design, bioeconomy education, circular economy, co-creation, educational games, Horizon Europe.

1 INTRODUCTION

In order to raise awareness and inform the young generations (ages 4 to 19) about the circular and sustainable bioeconomy, the Horizon Europe GenB [1] project has launched a series of educational games aimed at engaging young people across various age groups. The games — *BioHeroes: Let's Save the Planet!*, *The Bio Race*, *Green Chat Quartet*, and *Escape4Future- Chemistry Meets Circular Bioeconomy* — merge entertainment with learning about sustainability and bioeconomy. These games

are part of the GenB educational Toolkit [2], a curated set of resources designed to enhance bioeconomy learning and offer educators accessible science education tools.

GenB overall objective is to raise the Generation Bioeconomy (GenB), aware, sensitive and interested on environmental issues, sustainability and circularity, responding to needs emerged from several global and European priorities and policies, including the updated 2018 EU Bioeconomy Strategy [5], the European Green Deal and the 2030 Agenda for Sustainable Development. In fact, the creation of a European sustainability competence framework is a key policy initiative outlined in the European Green Deal, serving as a catalyst to advance environmental sustainability learning within the European Union. GreenComp [6] identifies a set of sustainability competences designed to inform educational programmes, enabling learners to acquire the necessary knowledge, skills, and attitudes. It features four interconnected competence areas: "embodying sustainability values," "embracing complexity in sustainability," "envisioning sustainable futures," and "acting for sustainability". GreenComp provides a versatile reference framework for educational initiatives aimed at integrating sustainability as a fundamental competency.

UNESCO identifies Education for Sustainable Development (ESD) as a vital component of Sustainable Development Goal (SDG) target 4.7 [7] (Sustainable Development and Global Citizenship) and a facilitator for achieving all 17 SDGs. ESD equips individuals with the knowledge, skills, values, attitudes, and behaviours needed to foster a sustainable way of life that benefits the environment, economy, and society. It promotes informed decision-making and collective action to transform society and safeguard the planet. ESD focuses on three core dimensions: (1) Cognitive, which enhances critical thinking and information processing; (2) Socio-emotional, which fosters social skills, empathy, and emotional intelligence; and (3) Behavioural, which promotes positive actions and sustainable practices. Through ESD, learners build both cognitive and non-cognitive skills, such as critical thinking, collaboration, problem-solving, managing complexity and risk, resilience-building, systemic and creative thinking, and are empowered to act responsibly as global citizens ([8], [9]). In this context, to foster sustainability education, GenB integrates innovative educational approaches, such as experiential learning, problem-based learning, collaborative learning, and game-based learning (GBL).

The paper analyses the application of this interactive and participatory methodology on the educational games focused on bioeconomy, emphasising the impact generated on more than 740 participants, including students, teachers and parents, who have been involved in the project activities. In addition, the project methodology includes the integration of STEM (Science, Technology, Engineering, and Mathematics)/STEAM (Science, Technology, Engineering, Art, and Mathematics), giving students the opportunity to tackle real-world problems and find sustainable solutions through science, technology, engineering, art and mathematics. Through science, the skills of young people are strengthened.

These human-centred approaches share common goals of promoting an engaging, meaningful and personalised learning experience, fostering 21st-century skills [10] and competences identified as crucial for raising a generation that is aware of, sensitive to, and interested in environmental and sustainability issues, thereby preparing students for real-world challenges.

Building on the educational and pedagogical frameworks, as well as the overarching objectives outlined above, the GenB project has designed a series of educational games grounded in active learning methodologies and a human-centred approach. The implementation and outcomes of these games are elaborated upon in the following sections.

2 METHODOLOGY

The four educational games developed within the GenB project target a diverse range of young audiences, including primary school students (4-8 years old), secondary school students (9-13 years old), and high school students (14-19 years old).

2.1 Educational objectives and pedagogical framework

The educational objectives of the GenB project focus on fostering a comprehensive understanding of bioeconomy concepts while promoting 21st-century skills, including critical thinking and creativity. Through GBL methodologies, the developed games aim to bridge theoretical knowledge with practical application, enabling participants to engage in experiential and exploratory learning. This approach supports competency development tailored to various age groups, reinforcing the practical relevance of bioeconomy education.

The primary components of the pedagogical framework underpinning the development of the games include: (1) game-based learning, (2) explorative and experiential learning, and (3) collaborative learning and co-creation. These approaches were strategically integrated to ensure that the mentioned educational objectives aligned with the goals of the GenB educational project and the GenB project.

The collection developed in GenB uses a GBL approach to boost student engagement and motivation while facilitating understanding of complex topics [3]. Play-Based Learning emphasises the importance of play as a natural and essential part of childhood learning, supporting cognitive, social, emotional, and physical development. Through both structured and unstructured play, children enhance collaboration, problem-solving, creativity, and strategic thinking, all of which contribute to meaningful learning.

The methodology further uses explorative and experiential learning, which emphasises learning through discovery and direct experience followed by reflection, to develop deeper understanding and practical skills. In this context, the teacher's role is to guide rather than instruct, helping students as they engage in self-directed inquiries that connect theoretical knowledge with practical applications.

These pedagogical strategies not only improve cognitive skills but also enhance students' ability to innovate, adapt, and collaborate in a rapidly changing world, thus contributing to the development of 21st-century skills [13]. In this way, the GenB educational games build on innovative pedagogical approaches, prioritizing student agency, real-world relevance, critical thinking, and the holistic development of the learner.

Games in education not only improve academic performance but also foster an interactive and cooperative learning environment, preparing young people to address real-world challenges [4]. Moreover, the integration of STEM/STEAM principles within the games design encourages interdisciplinary thinking, where students engage with science, technology, engineering, arts, and mathematics in practical, inquiry-driven contexts. This alignment with STEM/STEAM approaches encourages students to explore real-world problems and strengthens students' ability to solve complex problems through hands-on activities, promoting deep learning and critical thinking ([11], [12]).

2.2 Design methodology and validation

In the development of the games, which were designed during the first and second years of the GenB project (2023-2024), a HCD approach was adopted. This approach involved the active participation of over 740 participants, including students, teachers, parents and experts during a series of co-design and validation workshops. Students from primary and secondary schools, together with their teachers, actively participated across three European countries —Italy, the Netherlands, and Spain—partners of the GenB Project— to contribute to the ideation, design, and testing of the games. Their involvement aimed to enhance the games' relevance, usability, and effectiveness in delivering the intended messages. The iterative and participatory process enabled adjustments to align the games with users' educational needs and preferences. In the idea and concept definition phase of the games, specifically for *The Bio Race* and the *Escape4Future*, co-creation activities were carried out, within the framework of the Italian Living Labs.

During the validation phase, initially through rough prototypes and later through more advanced iterations for some games, all four games were tested. Several rounds of validation were conducted by experts in education, bioeconomy, gaming, pedagogy, child behaviour, and design to ensure technical accuracy and pedagogical effectiveness. Feedback was gathered through observation, focus groups, questionnaires, and think-aloud methods. User feedback from teachers, students, parents, and experts in game design and bioeconomy was primarily gathered through observations by educators and technical experts, as well as interviews with stakeholders. This process focused on the pedagogical effectiveness and usability of the games, assessing user engagement and gameplay clarity. Based on the feedback, iterative adjustments were made to refine the content and improve the user experience. A qualitative analysis of this feedback guided the development of the games and their iterations, ensuring they met educational objectives while remaining accessible and enjoyable for diverse audiences.

2.2.1 *BioHeroes: Let's Save the Planet!*

In *BioHeroes: Let's Save the Planet!,* professional profiles and their associated tasks were initially selected through a literature review, ensuring the concepts were both relevant and accessible to the target audience. Scientific validation by experts from partner Biomass Technology Group BV (BTG) guaranteed the technical accuracy and appropriateness of the content for users. The design iteration began with internal playtesting sessions involving AIJU, the Technological Institute for children's

products and leisure, with experts in child behaviour, toy market analysis, child development, and toy design (Fig. 1, left panel).

Figure 1. Internal playtesting of BioHeroes: Let's Save the Planet! (left panel) and validation gameplay session with the target group (right panel) © 2024 Clara Blasco-López (AIJU).

Validation activities included collaboration with 23 international educators during the "Future Classroom Lab Workshop: Supporting STEM Educators" in Brussels (19-20 March 2024), where the game's educational effectiveness was assessed. Large-scale validation occurred at the AIJU Toy Lab Experience in Spain, involving 323 children (aged 5–10) and 22 teachers in iterative testing sessions from March 2024 to January 2025 (Fig. 1, right panel). Critical feedback was provided, leading to the simplification of rules, refinement of instructions, and graphical redesigns to enhance user intuitiveness. This iterative process ensured the game met user needs and expectations, reinforcing the principles of human-centred design (HCD).

2.2.2 The Bio Race

The Bio Race game was co-designed and prototyped collaboratively with students of two Elementary classes (Rome, Italy) and external experts, within a co-creation and validation process led by APRE - Italian Agency for the Promotion of European Research (Fig. 2)

Figure 2. Prototype of the game by students during the Living Lab (Rome, Italy).

The co-design and validation process was conducted for two months (March-May 2023) and through a Living Lab process in two classes of a primary and lower secondary school in Rome. The living lab included four co-creation workshops (co-ideation, exploration, experimentation, evaluation). In September 2023, a focus group with experts was also conducted as part of the evaluation phase. Feedback for the game *The Bio Race* was collected from parents, stakeholders and external experts through quantitative and qualitative questionnaires, as well as focus group discussions during and after gameplay. The prototype was further played and tested in an open school event ("Sustainability Day", May 2023) involving parents and external stakeholders where students took on the role of "experts".

2.2.3 Green Chart Quartet

BTG drafted the *Green Chart Quartet* game content and SunnyConcepts created two distinct digital designs for the quartet game. These designs were tested with visitors of Museon Omniversum (education museum located in The Hague) to assess their effectiveness and design preferences. The feedback received was key in refining the draft game content and design, ensuring it to be a valuable

resource for both students and parents. Pilot versions of the *Green Chat Quartet* game, with large playing cards, were put on display at Dutch festivals (e.g., the European Night of the Researchers and Kleer'nzooi XXL), to collect additional feedback. Incorporating all feedback, the first edition of the quartet game was released in November 2024. The quartet game can be played at Museon Omniversum and is also for sale in the museum shop.

2.2.4 *Escape4Future*

The design and validation process of the *Escape4Future* game was developed collaboratively by GenB project partners in partnership with students and teachers from ITT Montani high school during the 2022/2023 academic year, as part of a living lab. These living labs within the GenB project aimed to co-create innovative formats to stimulate young people's awareness and interest on green chemistry and circular bioeconomy. The game was played at three large-scale events (Fig. 3): Maker Faire in Rome (20/10/2023), Fermamente in Fermo (22/10/2023), and EU Researchers' Night (27–28 September 2024). It was played by groups of students (ages 6 to 23), parents, and teachers in 20 sessions, with approximately 330 participants, who provided feedback for the game's validation and testing. The game was adapted according to participants' age and skill levels, ensuring a balance between enjoyment and the sense of accomplishment in solving the puzzles.

Figure 3. Large-scale event testing of the Escape4Future game.

3 RESULTS

This section presents the outcomes of the GenB project's educational games, designed to engage various age groups and educational contexts. These tools offer resources for teachers, students, parents, and other relevant stakeholders with resources to enhance understanding of bioeconomy concepts, including sustainability topics such as green chemistry, bioeconomy professions, and bio-based products. Available in board, card, and escape game formats, the games are suitable for both formal and non-formal educational settings. Three of the four games are freely downloadable, while the *Green Chart Quartet* is offered as a printed card game, requiring professional printing for production.

The following subsections present the development of these tools, emphasising active learning methodologies and human-centred approaches, aligning with the project's goal of engaging youth in bioeconomy and sustainability.

3.1 BioHeroes: Let's Save the Planet! - card game (age group 6 and up)

The *BioHeroes: Let's Save the Planet!* is an educational card game aimed at students aged six and above, designed for two to six players. The primary goal of the game is to raise children's awareness of bioeconomy professions and their importance in fostering sustainable development. Through gamification, participants learn about the roles and responsibilities of various professional profiles while developing skills such as empathy, teamwork, and an understanding of sustainable practices.

The game explores key bioeconomy topics such as sustainable resource use, circular production, and environmental stewardship through dynamic scenarios in cities, rural areas, factories, and other settings. Players engage with principles like local consumption, waste reduction, sustainable logistics, and eco-friendly product design. The gameplay encourages critical thinking and problem-solving as players navigate interconnected systems that showcase the complexity of sustainable production and consumption. By simulating processes like resource recovery and biogas production, the game helps

players understand how individual actions and professional roles contribute to a sustainable bioeconomy, while promoting environmental awareness and collaboration.

3.1.1 Game architecture and gameplay mechanics

The game employs an immersive narrative in which the world is threatened by environmental imbalances, and only the bioeconomy can restore equilibrium. Players assume the roles of professionals such as biotechnology researchers, bio-based farmers, transporters, sellers, waste managers, and consumers. The objective is to complete the tasks associated with each profession to save the planet. The game includes three types of cards: profession cards, task cards, and action cards (Fig. 4).

Figure 4. Front design of the BioHeroes: Let's Save the Planet! cards. Created and owned by AIJU. Design by Manu Camacho, Agencia Magnet. © 2024 AIJU.

The action cards, such as "Recycling" and "Lack of Resources," introduce strategic dynamics, allowing players to progress or hinder opponents. Two play modes are available: 1) *BioHeroes Discover the Tasks* for beginners, offering a simplified introduction, and 2) *BioHeroes Get to Work* for more experienced players, providing a greater challenge.

3.1.2 Innovative features and pedagogical contributions

The *BioHeroes: Let's Save the Planet!* card game uses image-based representations of bioeconomy professions and tasks, overcoming language barriers and eliminating the need for translation. Each card provides detailed visual depictions of professional activities, effectively conveying general actions alongside specific tools, techniques, and sustainable practices. This visual approach makes complex bioeconomy concepts more engaging and understandable. The game includes detailed instructions for educators to integrate bioeconomy tasks into the classroom, enhancing its pedagogical utility. This feature also encourages the development of supplementary didactic materials, supporting active learning methodologies and facilitating its integration into formal education settings.

Regarding challenges in the development, a major difficulty was presenting complex scientific concepts in a way that was simple for younger players yet detailed enough for older ones, achieved through visual cues that conveyed technical information without overwhelming. Designing an aesthetic that appealed to a wide age range was also crucial, with elements that resonated with both younger and older players. The game was text-free to avoid translation issues and was designed for easy printing on A3 paper, reducing resource needs. It needed to be fun, educational, and pedagogically sound while communicating complex bioeconomy-related concepts. The game's mechanics had to be intuitive enough for educators to explain quickly and facilitate multiple rounds within a typical 50-minute classroom session. The ultimate goal was to create a game that was engaging, easy to understand, and aligned with bioeconomy concepts.

3.2 The Bio Race - educational board game (age group 9-13)

The Bio Race educational board game aims to increase youngsters' awareness on the sustainable and circular bioeconomy and bio-based products. The game is targeted for students in the elementary and low-secondary school aged 9-13.

The game addresses essential bioeconomy concepts and processes, exploring the processes related to the production of bio-based products and the current possibilities of the sector that align with a circular and sustainable development. The purpose of this material is to increase the awareness and knowledge of the sustainable and circular bioeconomy and its applications.

3.2.1 *Game architecture and gameplay mechanics*

During the game, players (designed from 4 to 6 players) engage in activities, quizzes, and interactions aimed at creating new bio-based products from specific biomass found in different environments (city, forest, countryside and seaside) and energy units. As they complete assigned recipes to manufacture the bio-based products, players earn Sustainability Points. To do this, players must move their own Bio-Character counter around the board, collecting the required Biomass and Energy Units, according to the Recipe to complete. A recipe is considered completed when the required Biomass and Energy Units are transformed into a Bio-Product by visiting the Bio-Refinery, and it will yield an amount of Sustainability Points depending on its difficult. The game can be played in two versions, depending on the players' age: the simple version, where players complete four bio-formulas to finish, or the pro version, where they complete bio-formulas in four different types of environments.

3.2.2 *Innovative features and pedagogical contributions*

The Bio Race engages young learners in understanding sustainable and circular bioeconomy principles. Its gameplay versions accommodate varying age groups and cognitive abilities. The integration of individual and collaborative tasks, quizzes, and interactive challenges fosters critical thinking, teamwork, and problem-solving skills. By simulating the creation of bio-based products from diverse environments and actively participating in different steps of bio-based production, players develop a hands-on appreciation for bioeconomy processes and the importance of sustainable practices. The game leverages innovative formats, such as inquiry-based learning and manipulative learning, to produce engaging educational materials. It empowers youth to become agents of change in their communities and exemplifies a participatory approach to educational innovation through co-design and validation.

3.3 Green Chat Quartet - card game (age group 9 and up)

The *Green Chat Quartet* is designed for elementary school children aged 9-13 years. The primary educational objectives of this card game are to introduce young learners to various types of biomass and their associated bio-based products. It aims to foster an understanding of bioeconomy concepts, enhance critical thinking skills, and promote collaborative learning. The game also serves as a tool to stimulate interest in environmental education and sustainability, making learning both enjoyable and memorable.

The *Green Chat Quartet* comprises 12 sets of cards, each representing a distinct type of biomass and three bio-based products derived from it. Overall, these categories encompass agricultural biomass and residues, biomass from household waste, as well as innovative biomass sources such as mycelium. Rather than being perceived as waste, these materials highlight the potential within the bioeconomy and circular economy, potentially altering perspectives on waste management. Each card contains a fun fact about the biomass and product, providing additional educational value.

3.3.1 *Game architecture and gameplay mechanics*

Quartet is a deck card game where the goal is to collect four cards in a specific category, forming a quartet, and to gather as many quartets as possible. The cards are shuffled, and an equal number are dealt to all the players, who hold them without revealing their hand to other players. The player to the dealer's left starts by asking another player if they had a certain card which would help the player create a quartet. If the player does have the card, then they hand it over. If the player does not have the card, then it becomes their turn to ask. When a quartet is created, or a complete quartet was dealt, then the cards creating the quartet are placed in front of the player. Also, s/he shall read out at least one "fun fact" from that set aloud. The game ends when all the quartets have been created. The winner is the person with the most quartets, and requires no moderator (Fig. 5).

Figure 5. Four of the categories of the Green Chat quartet game.

3.3.2 *Innovative features and pedagogical contributions*

Educational games like quartet provide a fun and dynamic way to reinforce learning concepts, promote teamwork, and develop critical thinking skills. By incorporating educational content into a familiar and entertaining card game format, children are more likely to retain information and develop a positive attitude towards learning. This approach can also cater to different learning styles, ensuring that all children are engaged and actively participating in the educational process. Additionally, the inclusion of fun facts on each card encourages curiosity and further exploration of the topics covered.

3.4 Escape4Future - Chemistry meets Circular Bioeconomy (age group 13-19)

The escape game *Escape4Future - Chemistry meets Circular Bioeconomy* is designed for high school students (aged 13 to 19), with the support of one or more facilitators who set up the experience and deliver the educational content connected to the game. The game accommodates up to 15-20 players per session. Its primary goal is to raise young people's awareness of green chemistry and circular bioeconomy, fostering their understanding of sustainable practices and the challenges posed by unsustainable consumption patterns.

Escape4Future combines inquiry-based learning with gamification to enhance knowledge retention and skill development through engaging escape game mechanics. The game address's critical themes of green chemistry and bioeconomy, challenging players to solve puzzles and complete tasks through hands-on experiments or games that promote a sustainable and circular lifestyle. The game enhances learning through fun and motivation by encouraging exploration and problem-solving, while also consolidating knowledge and fostering transversal skills such as teamwork, critical thinking, and creativity.

3.4.1 *Game architecture and gameplay mechanics*

In *Escape4Future*, players face the challenge of a planet trapped in a linear consumption model—producing, using, and discarding products—leading to issues such as climate change, resource scarcity, and the proliferation of non-renewable waste. To "escape," players must solve six interconnected enigmas (Fig. 6) within a 30-45 minute timeframe. The facilitators can adjust the game's difficulty level depending on the players' skills and age.

Figure 6. The Escape4Future Mission and one of the enigmas to be solved by the participants.

3.4.2 *Innovative features and pedagogical contributions*

The *Escape4Future* game stands out for its innovative integration of inquiry-based learning and gamification, creating an engaging educational experience. Its immersive narratives and enigmas, rooted in real-world challenges like plastic waste and circular bioeconomy, foster critical thinking, collaboration, and creativity. The modular design enables facilitators to adapt the game's complexity to different age groups and skill levels, ensuring accessibility and relevance across diverse educational settings. The emphasis on experiential learning enhances content retention and equips players with essential skills for addressing sustainability challenges, aligning the game with active learning methodologies.

4 CONCLUSIONS

The GenB project's iterative design and validation process effectively aligned with the project's objectives, engaging target audiences and offering an accessible means of learning complex bioeconomy concepts. Despite certain limitations, feedback confirmed the games' potential to meet educational goals, demonstrating the viability of GBL in enhancing engagement and knowledge retention among young learners. The results of the GenB project corroborate previous studies that highlight the effectiveness of educational games in promoting engagement and understanding of complex topics [14]. However, this study specifically addresses the niche subject of bioeconomy, showcasing the ability of educational games to convey specialised content in an engaging way, while also offering co-created, low-cost, low-resource games as an added advantage.

The methodology employed in the GenB project faced some limitations related to geographic concentration, sample diversity, and testing environments. The games were primarily tested in the countries where they were developed—Spain, Italy, and the Netherlands—resulting in contextualised cultural and linguistic specificities in the feedback. Additionally, some games were tested using rough prototypes, which may have compromised the consistency and quality of the user experience. Despite the lack of refinement, prototypes are valuable tools for fostering creativity, iterative learning, and problem-solving, enabling ongoing improvement of the user experience [15].

Data collection varied across the games, with larger, more diverse samples for some, and smaller groups for others. For certain games, feedback was primarily gathered from teachers and experts during their observations and interactions with students, as well as from bioeconomy experts, child behaviour specialists, and game designers. However, games like *The Bio Race* and *Escape4Future*, which incorporated a co-creation process from the design phase, benefited from direct input from end-users.

Although the data collection methods—primarily qualitative (interviews, focus groups and observations)—provided valuable insights, they may have lacked the objectivity and consistency needed for a comprehensive evaluation. The varying experience levels of participants with the games and bioeconomy concepts may have influenced the feedback. While the games were effective in conveying bioeconomy content, their impact on behavioural change was not fully assessed. These limitations should be considered when interpreting the findings and evaluating the broader applicability of the GenB educational games.

Future research should aim to expand the geographic and cultural scope of game testing, incorporating more diverse populations to address the limitations of sample concentration in this study. Additionally, future studies should explore the long-term impact of GBL on engagement and behavioural change, especially in niche subjects such as bioeconomy and sustainability education. Further research should also consider incorporating a wider range of stakeholders to provide more comprehensive insights into the effectiveness of these educational tools.

In conclusion, the GenB project offers valuable insights into developing and validating educational games for bioeconomy awareness. Despite some limitations, the iterative design and validation process was effective, contributing to research on educational games promoting sustainable practices and bioeconomy understanding among young learners.

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