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Game on for Climate Action: Big Game Delivers Engaging STEM Learning

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Abstract: A decline in European students' interest in STEM subjects, exacerbated by the COVID-19 pandemic's disruption of education, has raised concerns about the continent's future workforce. To address this challenge, this study investigates the efficacy of the BIG GAME project methodology, a cooperative story-driven digital game approach designed to engage secondary students in collaborative environmental problem-solving. Implemented across Romania, Italy, Estonia, and Finland, this six-month study employed a mixed-methods design involving 62 teachers and 239 students in ten distinct game missions focused on environmental challenges. The quantitative results indicated significant improvements in students' transversal skills (teamwork, communication, and critical thinking), as reported by over 75% of teachers. The qualitative data emphasised the value of structured peer review in developing students' reflective practices. This research underscores the importance of teacher facilitation in game-based learning and problem-based simulations and highlights the potential of such methodologies to boost student engagement and environmental awareness. These findings suggest that the BIG GAME project approach could be a valuable tool for revitalising STEM education and cultivating future-ready citizens.

Keywords: STEM education; digital transformation; game-based learning; serious game; multidisciplinarity; environmental sustainability; collaborative learning

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1. Introduction

In light of the declining interest in science subjects and deteriorating learning outcomes due to the lack of digital skills across Europe, aggravated by the COVID-19 pandemic, the need to bolster STEM and digital education has become a global consensus, which is "essential to prepare students for future job markets that are increasingly reliant on technology and innovation" [1]. Sternadel [2] states, "the COVID-19 pandemic has exacerbated existing challenges in education, leading to a notable decline in student engagement and interest in science subjects across Europe". The OECD (2020) also reported that "*the impact of COVID-19 on education has been profound, with many students experiencing a decrease in motivation and interest in their studies, especially in subjects like science and mathematics*" [3]. The authors of [1] add that "*the disruptions caused by the pandemic have led to a reevaluation of*

students' interests in STEM fields, with many expressing concerns about their future engagement in science education". These statements highlight the pressing challenges that educators faced in maintaining student interest in STEM fields during the pandemic.

Bacovic et al. [4] provide evidence of this trend, noting that "*the share of graduates in STEM programs as a percentage of total tertiary graduates has decreased over the past two decades*". Despite an overall increase in the number of individuals with tertiary education and rising expenditure on education, the proportion of graduates in STEM fields has declined from 69% in 1998 to 62.6% in 2019. Furthermore, the EuroSTEAM comparative analysis report [5] underscores the need for engaging and enquiry-based STEM learning that encourages hands-on learning and the real-world application of STEM concepts.

This decline is further compounded by digital transformation, highlighting the importance of digital skills for all citizens [6]. According to the Digital Education Action Plan [7], despite women making up 54% of tertiary students in 2017, they only held 17% of tech sector jobs, many veering away from STEM subjects as they age. The recruitment of digital specialists is hindered by skill shortages, with 58% of companies facing hiring challenges and 78% citing skill gaps as investment barriers. Therefore, it is vital for basic education to equip students and teachers with the necessary skills to master various ICT tools and methods [8,9]. Schools and teachers play a crucial role in this effort, as they can significantly influence students' digital competencies, unlike the inconsistent resources available in homes. However, the OECD reports that many European teachers lack adequate digital skills due to insufficient time and opportunities to adopt new technology-based teaching methods [10].

Despite its crucial role in fostering innovation and economic growth, this downward trend poses significant challenges for the future workforce and societal advancement [11]. The situation can be attributed to a complex interplay of factors. Firstly, the perceived difficulty associated with these subjects, often due to their abstract concepts and complexity, leads to a lack of confidence among students. Secondly, traditional teaching methods may not effectively engage students, resulting in boredom and disinterest. Thirdly, the failure to demonstrate the practical applications of scientific concepts in real life can further alienate students from these subjects. Additionally, negative stereotypes about scientists and the misconception that science is only for the exceptionally gifted or socially awkward are reported to be a sound factor in the problem [12]. Finally, misconceptions about career opportunities in science fields, limited resources for hands-on learning experiences, and rigid curricula that prioritise rote memorisation over critical thinking have also been identified as contributing to deterring students from pursuing science subjects [13].

While some individual STEM subjects have been integrated into secondary school curricula [14], they often fail to foster the extensive multidisciplinary learning necessary for comprehensively exploring various scientific phenomena [15]. Therefore, the authors of [14] argue that "*more integration is not necessarily better*", emphasizing that "*integration should remain meaningful and purposeful*" to promote critical thinking and problem-solving skills effectively.

In response to these needs, it is essential to implement innovative teaching methods that emphasise real-world applications, improve the students' interest and motivation, reinforce the integration of technology into the classroom, promote diversity and inclusivity in the field, and provide adequate resources for practical learning experiences while introducing students to independent views and research skills [16].

In this context, the *BIG GAME project—Immersive and Multidisciplinary STEM Learning through A Cooperative Story-Driven Digital Game*, co-funded by the European Commission under the Erasmus Plus program, was a thirty-month initiative from 2021 to 2024 that aimed to address challenges identified at the European level by creating an innovative teaching strategy to make STEM education more accessible, engaging, and inclusive, particularly in the context of environmental subjects. The project brought together universities, research and training centres, and secondary schools to develop a new immersive methodology that combines digital storytelling with serious games. This methodology was specifically

applied to environmental issues, engaging secondary school teachers and students aged 11–16 across partner countries, including Finland, Italy, Estonia, and Romania [17].

This article presents the BIG GAME methodology and the challenges resulting from its application with the following expected aims: (1) to promote STEM education by fostering interest and proficiency in science, technology, engineering, and mathematics (STEM) by employing a multidisciplinary learning approach; (2) to offer an online and hybrid learning model that can facilitate digital transformation within schools; (3) to enhance the digital skills of teachers and students; (4) to raise the awareness of students about environmental and climate change.

2. Theoretical Framework

2.1. The Use of Digital Storytelling in STEM

Digital storytelling, a key component of digital transformation in education, has been empirically shown to be a potent pedagogical tool [18–20]. It leverages technology to create narrated visuals, fostering creativity, critical thinking, and digital literacy, thereby making learning more engaging and interactive. When adopted within the STEM education context, research indicates that digital storytelling can bring abstract concepts to life, making them more understandable and relatable [21–23]. It allows students to apply their knowledge in real-world scenarios, thereby enhancing their problem-solving and research skills [24]. Furthermore, it promotes collaboration and communication, essential skills in the STEM field [25]. Thus, digital storytelling not only enriches the learning experience but also prepares students for the digital future [26].

As defined by Bruner [27], storytelling is a series of events or mental states that gain meaning within the plot sequence. It is a valuable teaching strategy that makes disciplinary content easier to understand and remember. It aids learning by linking stories chronologically and thematically, allowing students to integrate and organise information effectively.

Digital narratives enhance learning by making students active participants in organising experiences within narrative structures following a cause-and-effect logic. This helps make sense of information and supports educational activities in various disciplines, including STEM, by making learning interactive. Moreover, being effective in developing students' cognitive skills and engaging students in complex activities and finding meaning in concepts involves drafting interactive non-fiction texts or creating fictional stories, reporting field experiences, and personally reworking concepts and content for skill-based teaching.

The key aspects of digital storytelling include writing speed, commenting speed, source verification, and narrative development. It broadens learning scenarios, allowing students to use their creativity to produce multimedia content within their curriculum. In addition, research indicates that storytelling can significantly enhance STEM education, particularly in engaging students and promoting deeper understanding [23,28]. Utilising narratives not only aids in conveying information effectively but also stimulates various parts of the brain, leading to enhanced retention and comprehension. For instance, studies have shown that storytelling activates the sensory and motor areas of the brain, fostering a more immersive learning experience than conventional teaching methods [2].

Furthermore, incorporating digital storytelling allows students to create and share their own narratives, thereby fostering essential skills such as research, writing, organisation, technology proficiency, and teamwork [29]. Students develop critical thinking, problem-solving, and communication skills by designing and presenting their stories, transcending traditional academic boundaries. Narratives provide a powerful tool for contextualising STEM concepts, enabling students to connect with the subject matter more deeply. For example, exploring real-life stories like Henrietta Lacks' immortal cells not only teaches biology but also raises ethical and social issues, encouraging critical analysis and empathy among students [30].

Research has consistently demonstrated that storytelling, which involves structuring a narrative around a protagonist and their events, understanding the target audience, and

choosing the appropriate medium, plays a crucial role in educational contexts [31]. Studies have shown that storytelling is effective in scientific dissemination online [32], fostering interdisciplinary learning [33] and developing essential workplace soft skills [34]. By facilitating the engaging learning of disciplinary content, storytelling promotes problem-solving, links different concepts, and enhances memory retention [35]. Additionally, storytelling can be designed to incorporate active learning elements. Storytelling also fosters team play by encouraging the communication and exchange of ideas, thus promoting exploration and creating interdisciplinary links [36].

Finally, digital storytelling's immersive nature naturally complements gamification's dynamic elements, creating a synergistic blend that enhances educational experiences. When combined, these approaches leverage narrative engagement and interactive game mechanics, enriching the learning process through increased motivation and deeper cognitive involvement [37].

2.2. Games and Learning Performance

As an educational strategy, game-based learning is known to leverage the learning process by infusing it with elements of playfulness [38]. Unlike traditional methods, using games in teaching offers students greater autonomy over their learning journey [39]. They can select from various paths to demonstrate their knowledge, opting for assignments that resonate with their interests and strengths, such as papers, projects, or digital artefacts.

When games are viewed as supplementary tools for skill and procedural knowledge development, they encompass a range of skills beyond teamwork and problem-solving. These include cooperation, negotiation, and communication skills, as well as critical and scientific thinking, reasoning, and argumentation. Additionally, games promote hand–eye coordination, quick problem-solving, synthesis, and analysis. They also foster leadership qualities, experiential learning, active listening, and the application of problem-solving in new collaborative contexts. Furthermore, games provide a platform for formulating valid answers and exploring topics such as climate change and potential preventative measures [40,41].

Embracing the concept of "safe failure", for example, the digital game provides low-stakes opportunities for learners to refine their skills through quizzes, peer activities, and multiple assessment attempts [42]. Instead of penalising mistakes, the approach focuses on "levelling up", rewarding students with points as they progress and achieve milestones. Research indicates that game-based learning not only boosts performance in practical tasks but also enhances learning motivation, fosters attitude and behaviour changes, promotes collaboration, and heightens learner engagement [43].

Serious games, a term coined by Abt [44], extend this concept by designing games with purposes beyond mere entertainment, focusing on education, training, or social change. These games leverage the engaging nature of play to facilitate deeper learning and skill development in various contexts. Research has shown that serious games can enhance motivation, foster critical thinking, and promote collaborative problem-solving among players [42,45]. Recent studies have explored their effectiveness in addressing complex issues such as environmental sustainability and climate change education, demonstrating their potential to create immersive learning experiences that resonate with learners [46,47].

In addition, empirical evidence indicates that students immersed in games' instructional paradigms exhibit superior learning outcomes, characterised by heightened levels of engagement and motivation [45]. Finally, scholarly investigations consistently underscore the positive correlation between game-based learning environments and enhanced student performance [48].

3. Research Design

3.1. Research Phases

The research design of the BIG GAME project consisted of two main phases: exploratory and piloting. The initial exploratory phase was conducted to gather insights from

students and teachers about their experiences and preferences related to gaming and environmental issues. This phase aimed to understand participants' gaming habits, preferences, and concerns, which informed the design and implementation of the BIG GAME project methodology. The findings from this exploratory phase were crucial in shaping the piloting phase of the project, ensuring that the game-based learning environment was tailored to meet the interests and needs of the students.

During the piloting phase, students applied the BIG GAME project methodology in classrooms by challenging to solve missions related to local environmental issues in small groups. This involved developing their investigations and suggesting one or more solutions to address these issues, searching for reliable and diversified resources to support their hypothesis and presenting their findings in English to enhance their communication skills. Teachers facilitated the process by supporting research efforts and managing group dynamics.

The final evaluation process included assessing the digital products created by the students, which detailed their research findings on environmental challenges. Peer review mechanisms were employed to enhance the learning outcomes and promote a collaborative learning environment. A comprehensive survey was conducted after the pilot phase to gather the participants' opinions and perceptions regarding the project methodology, ensuring the systematic collection and analysis of the feedback.

The outlined phases were guided by the following research questions:

- RQ1: How does participation in the BIG GAME project influence students' awareness and understanding of environmental issues?
- RQ2: What specific activities within the BIG GAME project do students find most and least engaging in developing their STEM skills, and what challenges do they encounter during the project phases?
- RQ3: How do teachers perceive the effectiveness of the BIG GAME project in enhancing students' learning experiences and fostering environmental awareness?

3.2. Data Collection Instruments

The BIG GAME project employed a mixed-methods approach to data collection, utilising both quantitative and qualitative instruments to gather insights from students and teachers. The primary tools used were surveys and feedback questionnaires designed to assess participants' experiences, perceptions, and outcomes related to the project. These surveys included a combination of quantitative and qualitative questions aimed at evaluating engagement levels, skill development, and overall satisfaction. While the specific questions are not detailed, the surveys likely covered aspects such as the project's effectiveness in enhancing environmental awareness, its perceived impact on learning outcomes, and challenges faced during the piloting.

The validity of these instruments can be inferred from their design, which captures relevant data about the educational experience and the outcomes associated with the BIG GAME project. Ideally, these surveys were developed based on established educational theories and frameworks, aligning with the project's objectives of fostering critical thinking and environmental awareness. The reliability of the surveys would depend on their consistency in measuring the intended constructs over time, with standardised questions and a clear scoring system enhancing reliability. Pilot testing the surveys before full deployment could identify ambiguities or biases, further supporting their reliability.

In addition to surveys, feedback mechanisms such as peer reviews, teacher reflections, and experts' evaluations were utilised to gather qualitative insights into the project's impact. These mechanisms allowed the participants to provide constructive criticism and share their experiences, contributing to a richer understanding of the project's effectiveness. The validity of the feedback mechanisms is supported by their ability to capture nuanced perspectives that surveys may not fully address. Although the reliability of feedback can be more variable due to subjective interpretations, providing structured guidelines for giving feedback can enhance the consistency across responses.

3.3. Participants

The participants in the BIG GAME project included both students and teachers from various secondary schools across multiple countries. The following details outline the demographics, inclusion/exclusion criteria, and recruitment procedures for the research participants.

The student participants were primarily between 11 and 16 years old, with the majority (45%) in the 15–16 age range. Their demographic distribution was 69% from Romania, 11% from Italy and Estonia, and 9% from Finland.

The teacher participants comprised 62 educators, with notable representation from Italy (50%), Romania (37%), Finland (11%), and Estonia (2%). Among the teachers, 84% were female, 4.8% were male, and 11% chose not to disclose their gender. The teachers taught various subjects, including Biology (56%), Mathematics (42%), Geography (34%), and languages (50%).

The participants were voluntarily included in this study if they were secondary school students or teachers actively involved in the BIG GAME project. The focus was on students aged 11–16, ensuring the sample represented diverse experiences and perspectives from different educational contexts.

The recruitment was conducted through the project's network of schools in the participating countries. The teachers and students were invited to participate, and their involvement was facilitated by the project team. This recruitment process aimed to ensure diverse representation, gathering comprehensive insights into the effectiveness of the BIG GAME methodology.

However, priority was given to the teachers working in secondary schools who had the willingness to develop multidisciplinary STEM learning, support digital transformation by testing new digital teaching and learning methods and tools, and contribute to the fight against climate change by experiencing attitude-forming learning experiences and who also had interest in gaining experience and contributing to European cooperation in the context of school education.

The requisites for the teachers were the following: (1) a command of English (B1–B2); (2) teaching in subjects related to STEM; (3) the level of interest and motivation to carry out the BIG GAME activities; (4) full-time employees for at least one year in a school or working in other educational organisations involved in STEM teaching or interested in developing the STEM approach of the project's context in their institutions.

For students aged 11–16, the teachers prioritised admitting pupils who had learning difficulties, were at risk of exclusion or dropping out, and had poor basic skills and a history of school failure.

The entire participant selection process was designed to create a diverse and representative sample, providing valuable feedback on the BIG GAME project and contributing to understanding its impact on student learning and engagement with environmental issues.

4. Method

4.1. Exploratory Phase

In the first months of the project activities, an exploratory investigation was conducted to gather preliminary information that could help design a conceptual model of the BIG GAME methodology and a game environment based on the received feedback.

Recognising the value of player-centred and participatory approaches in serious game design [46], the project team involved teachers and students in the design process. The students' survey focused on their experience and preferences regarding games and their priorities and concerns relating to environmental issues. The teachers' survey focused on using games in their teaching and their potential for the students' learning progress.

The survey results of the exploratory research are described in the following sections.

4.1.1. Insights from Students' Survey on the Exploratory Research

The analysis revealed that most 11–16-year-old students prefer a real-world setting in the present day or the past for games. They enjoy overcoming challenges, competing against other players, experimenting, and discovering new things. As the results show, the students' primary preferences in gaming, ranked by importance, include overcoming challenges and improving at the game (51%), competing against other players (49%), and experimenting and discovering new things (37.05%). Creating and developing a character appeals to 25.90% of players, while immersing themselves in the story is favoured by 15.14%. Socialising with other players is the least prioritised, with only 10.36% showing interest. As one may conclude, this hierarchy suggests a strong focus on personal achievement and competitive elements, with creative and social aspects being less significant for most players.

The survey focused on understanding students' gaming habits and preferences to tailor a game-based learning environment. It found that a large majority of students spend a significant amount of time playing games: 35% play for more than an hour daily, 57% play for 30 min to an hour, and only 8% play for less than 30 min. The primary appeal of games for these students is the challenge and the opportunity to improve (51%), as well as the competitive aspect of playing against others (49%). This indicates that competition and personal achievement are crucial for maintaining their engagement.

Beyond these primary motivations, students also enjoy experimenting and discovering new elements within games (37.05%), and a notable portion likes to create and develop characters (25.90%). However, socialising within games is less important to them, with only 10.36% finding it an attractive feature. Interestingly, 10.76% of the surveyed students do not play games at all, which suggests a minority is either disinterested in gaming or has limited time to engage in it.

When it comes to game settings, most students prefer realistic environments set in the present or past, although 31.08% are also interested in near-future science fiction scenarios. The most popular game genre among students is action and first-person shooters (46.61%), which involve experiencing the game through the protagonist's eyes, a perspective that enhances the immersive experience.

In terms of social gaming preferences, half of the students enjoy playing online with others, whereas only 23% prefer playing with friends in the same room. Solo gaming is also an option but was not quantified in the same detail. The devices most commonly used for gaming are smartphones or tablets (60.16%), followed by PCs and game consoles.

Regarding in-game rewards, students favour points (38.65%) and prize items (33.07%) over other types of rewards like badges and leaderboards. These preferences indicate that tangible rewards and measurable progress are significant motivators for student gamers.

4.1.2. Students' Environmental Concerns and Awareness

The survey's findings highlight a significant awareness among students about key environmental issues, particularly climate change, air pollution, and water pollution. This awareness is crucial as it indicates a baseline understanding of environmental challenges. However, awareness does not always translate to concern, a more profound motivator for action. The survey results show that, while awareness of water pollution is high, it is not as great a concern for students as deforestation, indicating that students may perceive certain issues as more immediate or impactful.

The high levels of concern for climate change (33.86%) and deforestation (29.88%) suggest that these issues could be effectively used as central themes in the BIG GAME game-learning environment. Incorporating missions or challenges related to these areas could engage students by aligning with their existing concerns. For instance, challenges that involve reducing carbon footprints or virtual reforestation projects could resonate well with the students.

Moreover, the data imply that, while air pollution is both a recognised and concerning issue, its impact might be less understood in comparison to climate change and defor-

estation. This provides an opportunity for educational interventions within the game to deepen students' understanding and concern about air pollution. Interactive elements that simulate the impact of air pollution on health and the environment could enhance the game's educational value.

Additionally, the survey underscores a gap in concern for water pollution despite its high awareness, suggesting that students might not fully grasp its severity or immediate effects. Addressing this gap through the game by creating scenarios that show the direct consequences of water pollution on ecosystems and human health could be an effective strategy to elevate this issue in students' minds.

In conclusion, the survey provides valuable insights that were taken into account during the development of a game-learning environment tailored to students' environmental awareness and concerns. The game can foster a deeper understanding and proactive attitude towards these environmental challenges by focusing on the most concerning issues—climate change, deforestation, and air pollution. Furthermore, it can bridge the gap between awareness and concern for less immediately worrying but equally critical issues like water pollution, ensuring a comprehensive environmental education experience.

4.1.3. Insights from Teachers' Survey on the Exploratory Research

Regarding the enquiry into the game objectives, more than half of the respondents indicated that a game for students should aim at "Developing skills and procedural knowledge" and "Encouraging behaviour/attitude change". Additionally, nearly one-third of the respondents collectively viewed the game as a means to increase interest in the subject or to develop conceptual knowledge. In particular, as viable arguments for the last case, the following ones were noted: global concerns such as global warming, sustainability, and consumption, along with concepts related to common human identity and destiny; the practical application of language, literature, history, geography, and science in everyday life; the development of algorithms and strategic thinking; and the enhancement of social skills. Substantially, the essence of the answers may be outlined by the response of a teacher from Romania, who rightfully underlined that "*in theory, any subject—ranging from language and literature to STEM subjects and art—can be embedded in a game and became part of the game's plot*".

Instead, when viewing a game as a supplementary aid for skill and procedural knowledge development, beyond teamwork and problem-solving, a range of specific skills emerge, including cooperation, negotiation, and communication skills, along with critical and scientific thinking, scientific method and analysis, reasoning, and argumentation. Other highlighted skills encompass hand-to-eye coordination, the ability to provide quick and accurate solutions to problems, synthesis, and analysis, as well as leadership qualities, learning-by-doing, and active listening. Moreover, the application of problem-solving in novel, cooperative learning contexts is emphasised, along with the ability to formulate valid answers and comprehend climate change and potential preventative measures.

Teachers recognise that games can potently foster behaviour and attitude changes among students, understanding their potential to captivate children's attention and enhance classroom dynamics. They overwhelmingly agree on games' capacity to enhance student learning. The responses indicate that when the primary objective of a game is to promote behaviour and attitude change, the focus primarily revolves around environmental and social issues. Regarding social attitudes, teachers emphasise cultivating traits such as patience, respect for others, collaboration, and fair play while aiming to boost self-confidence and instil proper classroom behaviour. Additionally, they aim to foster habits of listening, accepting diverse opinions, building tolerance, and engaging with global issues to promote positive change. Concerning environmental issues, the emphasis is on actions like selective trash collection; caring for green spaces; promoting sustainable transportation; and reducing energy, water, and plastic consumption. Teachers also stress the importance of considering the environmental impact of consumer choices, including

the production processes of everyday devices, thus advocating for a holistic approach to environmental consciousness.

To sum up, the general core idea expressed could be summarised as follows: "*Teaching through games could lead to children being more immersed in studying than during a regular class; students can gain knowledge, but they don't use what they already know, they still act as they don't care*". Therefore, "*the aim should be to get them to actually do something, even though it might be less convenient, e.g., preferring public transport/a bike over a car. Also, what kind of sustainable change can pupils perform in their everyday lives, what kind of co-operational changes can they perform in their society, etc*.".

4.1.4. Teachers' Views on Environmental Challenges Faced by the Countries

To enquire about what kind of environmental challenges are faced/seriously recognised by your country, the highlighted challenges revealed during the exploratory phase and based on the teachers' views primarily revolve around environmental degradation and sustainability issues. In particular, they underlined that deforestation, the loss of biodiversity, pollution from coal and oil shale mining, and the use of unsustainable energy sources underscore the pressing need for conservation efforts and transitioning to renewable energy alternatives. Additionally, the teachers' concerns, such as waste management, microplastics pollution, and food waste, emphasise the importance of sustainable consumption and waste reduction practices. The mention of climate change's impact on agriculture, health, and rising fossil fuel prices further highlights the interconnectedness of environmental issues with socio-economic factors. Below, the country-per-country summary of the challenges specified is presented. Surely, these are broad categories, and the specific issues within each category can vary. Furthermore, these are the teachers' perceptions and may not fully represent the actual environmental challenges in each country.

In Romania, deforestation emerges as a pressing concern, with multiple references highlighting its significance. Issues surrounding waste management, including disposal, recycling, and landfill usage, are frequently mentioned, reflecting challenges in maintaining environmental cleanliness. Pollution, particularly air and water pollution exacerbated by urban traffic congestion, compounds environmental woes. Energy sustainability faces hurdles due to escalating fossil fuel costs and inadequate investments in green energy. Additionally, the educational landscape grapples with technical support deficiencies in classrooms and decision-makers unfamiliar with classroom realities. Beyond environmental concerns, Romania contends with external stresses, such as the conflict between Ukraine and Russia, as well as internal challenges like inflation and political instability.

Italy's environmental discourse is marked by a strong emphasis on recycling, encompassing efforts in waste sorting, reusing objects, and metal recycling. There is a notable push towards green living, characterised by initiatives to reclaim green spaces and increase overall greenery. Energy sustainability is a priority, with a focus on renewable energy sources, energy-efficient housing, and achieving energy autonomy. Climate change prompts various initiatives aimed at mitigating black carbon emissions. Sustainable agriculture and food waste reduction emerge as critical components of Italy's environmental agenda, alongside public health and equity concerns.

In Finland, climate change looms large on the environmental agenda, with discussions revolving around global warming and its pervasive impacts. Biodiversity loss, attributed to factors like microplastics and habitat destruction due to industries like wood and peat, underscores ecological concerns. Agriculture faces threats from extreme weather conditions, including droughts that jeopardise crop yields.

Waste management takes centre stage in Estonia's environmental dialogue, with a focus on trash recycling and effective waste disposal practices. Energy sustainability is a key consideration, with efforts towards adopting green and alternative energy sources, while navigating the continued use of coal. Climate change poses significant challenges, with concerns over global warming and its far-reaching consequences. Deforestation emerges as an environmental challenge alongside issues related to agriculture, including the impact of

hotter summers on crop cultivation and the environmental toll of intensive agricultural practices on water quality and soil health.

4.2. Piloting Phase

4.2.1. BIG GAME Learning Concept and Model

Based on the results achieved and the feasibility of game design with the available budget, the BIG GAME concept and model were designed according to the following features:

- Valorisation of mastery, competition, discovery, and roleplay of the students.
- Encouragement of problem-based simulations, in which teams of students roleplay as elite squads of experts tasked with tackling urgent environmental issues.
- Presentation of the missions (scenarios) taking place in a shared fictional world.
- Formulation and submission of the proposed solution to each scenario from the students.

The BIG GAME project methodology uses cooperative story-driven digital games to engage students in STEM education by solving fictional missions based on real environmental issues.

The key objectives of the BIG GAME methodology are as follows:

- Promoting STEM Interest and Excellence—by combining science, technology, engineering, and mathematics into a multidisciplinary learning framework, BIG GAME enhances education through digital gaming.
- Enhancing Digital Skills—the methodology helps develop digital skills for teachers and for students aged 11–16, promoting versatile learning in a digital environment.
- Raising Environmental Awareness—focusing on environmental and climate change issues, BIG GAME increases awareness and encourages students to participate in combating climate change.

Thus, the BIG GAME methodology uses serious gaming to create a unique educational experience, highlighting cooperative storytelling and digital interaction to meet its educational goals.

4.2.2. Game Environment in the BIG GAME Project

The simulation game is designed to be problem-based and seminar-style, where the student teams are encouraged to tackle urgent environmental issues and existing projections set in a fictional world: a near-future Earth. Some scenarios have more of a local flavour, while others speak to issues experienced globally.

The tone of the scenarios and in-game storytelling are urgent to convey the severity of the issues at hand, but they are also ones that offer players enough hope to avoid demotivation. The scenario submission procedure allows for the contribution of ideas from teachers, development team members, and invited experts, serving as the foundation for new missions within the game.

The development team crafts these missions, incorporating character dialogue, mission objectives, and necessary game assets. The submission form comprises several key sections, including a scenario description rooted in real-life environmental issues and requirements outlining success criteria, location, duration (emergency or long-term), problem type (climate change, loss of biodiversity, pollution, demographic, or agricultural), specific problem details, and possible solutions to ensure diversity in gameplay approaches. Additionally, references to reputable sources provide players with further information, and optional notes may include considerations or constraints for emphasis during gameplay. Thus, the BIG GAME concept and model prioritises students' mastery, competition, discovery, and roleplay. It involves a problem-based simulation where teams of students act as expert squads addressing urgent environmental issues presented as missions in a shared fictional world. Each team can formulate and submit proposed solutions to these scenarios.

The game environment is set in 2030, when Earth faces worsening climate challenges. In this context, the United Nations has formed the UN Anti-Apocalypse Force (UNAAF), and student teams respond to various environmental emergencies worldwide. During the piloting phase, access to the game was authorised upon registration through the project website https://big-game.eu-track.eu/ (accessed on 13 August 2024), with specific credentials provided to each team enrolled on the activity, as shown in Figure 1 below.

Figure 1. Access to the project game environment.

Once the team was inside the game environment, they could see the "mission data" and the "team information", as shown in the following Figure 2.

Figure 2. Inside the game environment.

In addition, there were three buttons: *briefing*, which showed the mission briefing as a dialogue with the game characters (Figure 3); *report*, which showed a text-based report (Google Doc) containing the mission information; and *submit*, which took each team to their empty mission solution template to submit their solution to the Evaluation Committee, including game designers, environmental and STEM experts, and secondary school teachers.

The mission data displayed all the information regarding the mission to be solved, such as the title, the status (for example, submitted), and the evaluation schedule.

In the team information, the team could see the team's name, the country of residence, the number of missions completed, and the results of the evaluation of the team.

The game's time was aligned with real-world time: a week in the game spans seven real-world days. Every two weeks, a new mission was released and could be accessed via the game's web portal. Each mission, focused on environmental problem resolution, had the same template, including a mission statement describing, along with photos, the urgent environmental problem that the UNAAF asked to be solved. This document, shown in the following figure, included some important local features to understand the setting, such as

the location and environmental features, to have all the information to start working like a researcher in the real world.

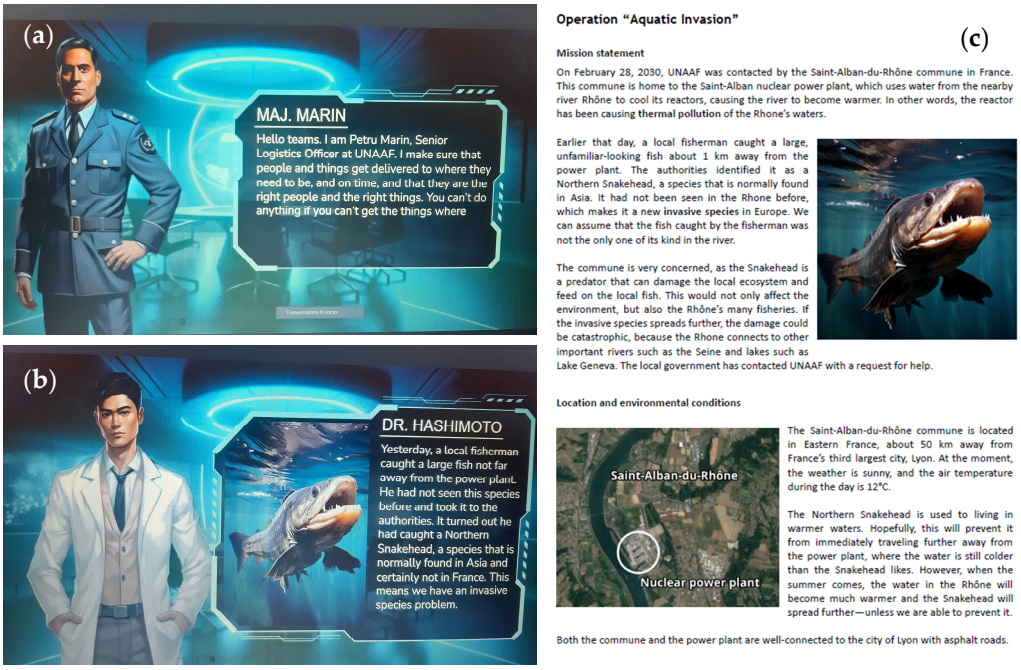

Figure 3. (**a**) One member of the UNAAF presenting the mission for the students' team; (**b**) one member of the UNAAF's scientific committee describing the main elements of the mission to deal with; and (**c**) the mission describing the environmental issues to be solved by the students' team. This example is the Operation "Aquatic Invasion".

After a new mission was released, each team of students researched independently (starting from references suggested in the mission), brainstormed solutions, selected and developed one, and submitted their proposed solution through the game environment, as shown in the following Figure 4: the web portal, adhering to the specified format.

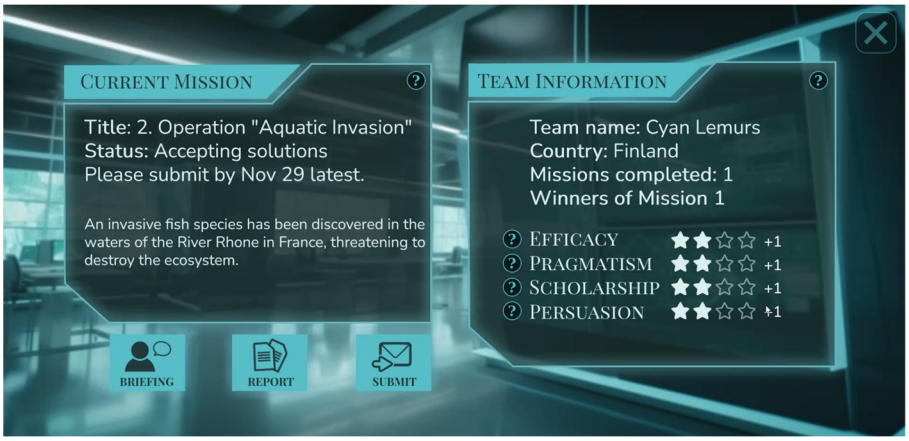

Figure 4. Students' team procedure for the mission submission inside the game environment.

The submissions were double-blind peer-reviewed using the website by the Evaluation Committee, which assessed and scored each mission based on the following criteria:

- **Efficacy**: how effective is the proposed solution at dealing with the problem (*i.e., would following the proposed steps make the problem disappear or at least minimise its negative effects?*)?

- **Pragmatism**: how realistic is the solution, considering available technology and limited resources (*i.e., not requiring thousands of workers to implement and not relying on futuristic technology that has not yet been invented*)?
- **Scholarship**: how well did the team do in their research (*as evidenced by how well they understand and use key terms, how relevant the sources listed on the final slide are, etc.*)?
- **Persuasion**: how well is the solution presented (*clear wording, good use of images, etc.*)?

The Evaluation Committee members evaluated each submission, grading each of the criteria above on a 1–5 scale (1 = poor; 3 = average; and 5 = outstanding) as specified in the following Table 1:

Table 1. Evaluation criteria grid.

CRITERIA	★	★★	★★★	★★★★	★★★★★
EFFICACY					
PRAGMATISM					
SCHOLARSHIP					
PERSUASION					

Based on this, teams were awarded +1 stars in one or more categories: the teams with a higher average score will earn more points than those with a lower score; however, every team earned at least one star.

Teams with the highest average score and having submitted the most sensible type of solution were declared the mission winners.

4.2.3. The BIG GAME Approach inside the Classroom

In addition to the activities to do in the game environment, the students were asked to implement several tasks individually, in groups, or in classes. The project team created the structure for the solution submission, and, therefore, the student teams were guided by a template. This guide document is suitable for STEM subjects, particularly considering environmental issues, and allows students to work together in multidisciplinary and interdisciplinary areas by facilitating their development of transversal and soft skills. It is constructed using a digital storytelling approach, presenting story-driven learning scenarios where students propose solutions to environmental problems.

In the classroom activities, the teachers' tasks included providing students with information on environmental issues, explaining the learning scenario setting, and optionally preparing a specific topic for study. For example, "Operation Black Ice" describes how teachers can present a particular topic. Whereas it was suggested that students aged 11–16 work in small groups of 3–4 members, the teachers could manage their classes as they see fit. The students' tasks began with researching the selected environmental issue, ideally focusing on local and specific problems. For instance, in Finland, students might address the endangered ringed seal or arctic fox, a species that cannot survive without snow.

At the same time, the students developed a scenario idea (e.g., a problem to be solved and setting), researched the environmental problem (following the model in Figure 5), proposed a possible solution, and prepared their scenario by analysing the problem.

After the research, the students presented their findings to the class, including any relevant materials such as pictures, videos, or articles, ensuring proper copyright checks. They delivered their research in English.

During this process, the teachers observed, helped, and encouraged students in their scenario work; assisted students in finding suitable references; and managed the groups in the class.

Following these steps, the teachers and students could effectively integrate the BIG GAME approach into the classroom, fostering engagement, creativity, and critical thinking skills, while addressing real-world environmental challenges.

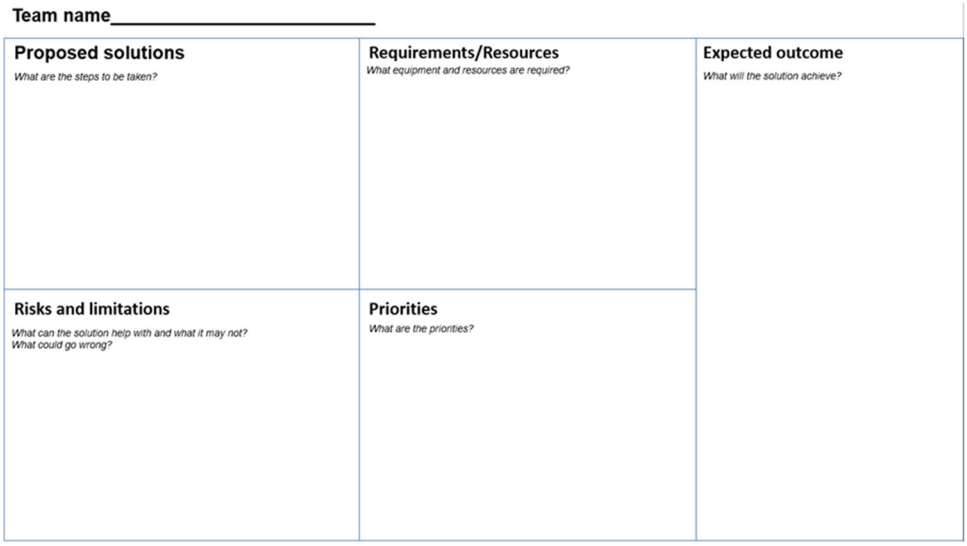

Figure 5. Model for students' research.

4.2.4. Assessment Procedures in the Classroom

In the classroom evaluation process using the BIG GAME approach, the initial step involved assessing the digital products created by the students, which described their scenarios and findings on the environmental challenges. This evaluation took place in front of the class, on school premises with the involvement of other classes, or by inviting environmental experts or participants from other schools.

To ensure effectiveness, a peer-review mechanism was employed. Peer review in the classroom significantly enhanced the learning outcomes within the BIG GAME approach by promoting a collaborative learning environment. The students received feedback from their peers and engaged in providing constructive criticism and insights, fostering a deeper understanding of the subject matter as they critically assessed and reflected on each other's work. Thus, the BIG GAME methodology integrates peer assessment as a critical component, allowing students to engage in reflective practices and collaborative decision-making. By evaluating each other's strategies and outcomes, the students gain valuable insights into the decision-making processes. This not only enhances their understanding of the game's objectives and the reasoning behind their choices but also enables them to learn from their peers, leading to a deeper comprehension of the implications of their decisions on the missions to tackle.

The aim was to encourage communication skills, teamwork, and empathy by having students consider diverse perspectives and offering supportive feedback. The peer review was guided by three to four questions formulated by teachers to assess the depth, coherence, and effectiveness of the scenarios.

4.3. The BIG GAME Competition Campaign and Training Activities Organisation

To recruit more secondary schools to participate in the piloting phase of the BIG GAME methodology and game environment, the project team launched a huge competition campaign in May 2023 (Figure 6) across partner countries by inviting secondary schools, in particular, student teams, to solve game missions on urgent environmental problems.

The competition followed a structured schedule, beginning with registered teachers receiving login details one week before the game commenced, allowing their teams access to the game environment. Once underway, the student teams engaged in three 10-day environmentally themed missions to avoid potential environmental disasters through offline and online tasks following the methodology described above. Guided by their teachers, the students navigated the game environment, researched solutions, and submitted their findings using the provided templates.

Figure 6. Some pictures designed and developed by partners for the competition campaign.

Once each team submitted their solution to a specific mission, the Evaluation Committee assessed the solutions based on the criteria selected (efficacy, pragmatism, scholarship, and persuasion). The results were released within four days of each mission's completion. The Committee's task was to meticulously evaluate the submissions to determine their effectiveness, practicality, academic rigour, and clarity of presentation. Their thorough evaluation ensured a fair and comprehensive assessment of each team's efforts.

The competition concluded with the announcement of the winners on December 20th, 2023. The award ceremony was held in the respective country by delivering the certificate and badges, as shown in Figure 7 below, designed for the BIG GAME competition to the students.

Figure 7. Badge designed for (**a**) the competition winner's team; (**b**) all the teams participating in the competition; and (**c**) the winner's team badge for the best game mission selection.

All the secondary students' teams desired to participate in the piloting phase without competition, so the project team established a digital bank, serving as the central repository for STEM education focused on environmental issues. Hosted on Google Drive, this platform offers a streamlined process for uploading and storing all the materials that teachers and students submit.

The teachers and students were encouraged to contribute to this digital bank by submitting educational resources for future use. They could select pre-designed missions or create their own using a scenario template and a short descriptive video, which was then emailed to the Evaluation Committee.

The Evaluation Committee engaged in another evaluation process for the 14 scenarios submitted following the criteria. Based on these criteria, the proposed solutions had to be realistically implemented, effectively address the problem, optimise limited resources, and be presented clearly and understandably.

The digital bank currently hosts 22 student-submitted scenarios and is accessible through the project website.

Besides the competition campaign, the project team organised and managed a series of training events (Figures 8 and 9), conducted both in face-to-face and virtual modalities, intending to reach a wide range of specialists, experts, and educators in the training sector, as well as secondary school teachers. These events were designed to effectively deliver the main ideas, methodology, and learning concepts of the project while also promoting the European contest through targeted campaigns. Spanning across Finland, Italy, Romania,

and Estonia, these training events engaged a total of 208 secondary school teachers, as illustrated in the figures below.

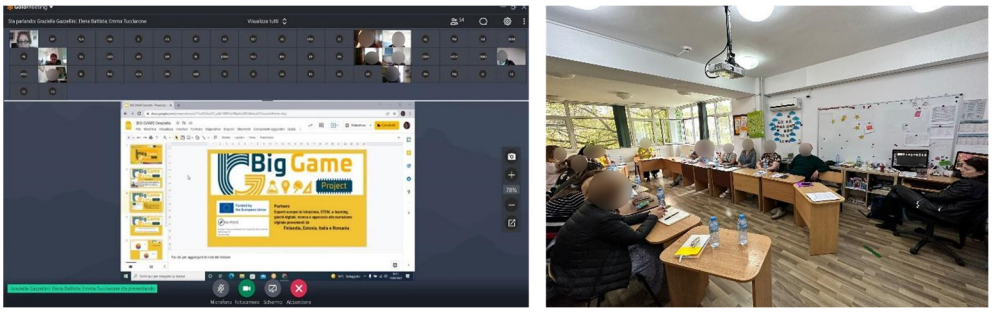

Figure 8. Some pictures of virtual and face-to-face training events organised by EUROED (Romania) on 20 October 2023 and 12 May 2023.

Figure 9. Some pictures of face-to-face and virtual training events organised by EU-Track (Italy) at *Fiera della Didacta* on 10 October 2023 and in collaboration with I.C. Maria Montessori (Italy) during the STEM Discovery Campaign 2022 and 2023 on 13 October 2022, 13 October 2023, 5 April 2022, and 4 November 2023.

In the end, 121 teams from 27 schools across four countries participated in the competition. There were twenty-four teams from Romania, six from Italy, nineteen from Estonia, and seventy-two from Finland, who collectively submitted 270 mission solutions.

5. Results

5.1. Teachers' Feedback

The survey gathered various insights from teachers to understand the impact of the BIG GAME project methodology and tools.

The responses to the question about the usefulness of the BIG GAME materials reveal a generally positive reception with some constructive feedback. As shown in Figure 10, the BIG GAME materials were highly valued for student engagement, with 47% of respondents describing them as extremely useful and 27% finding them useful.

The participants highlighted that the materials introduced new environmental scenarios, served as discussion starters, and facilitated student teamwork and collaboration. One respondent highlighted, "*The materials were a good starting point for discussions*", while another mentioned, "*The scenarios facilitated teamwork, collaboration, and mutual support, which are essential for the successful completion of an activity*", emphasising the role of the scenarios in promoting a successful activity through teamwork. In addition, the materials were praised for developing knowledge, transversal skills, and creativity. The teachers noted that they were fun for students, helped them use English, and motivated them well.

The clarity and accessibility of the structured format were particularly praised, along with the materials' effectiveness in developing knowledge and transversal skills. Comments such as "*The material was excellently structured*" and "*All was extremely clear*" underline how the structured format provided essential guidance, making it easier for students to

understand and complete tasks. The simplicity and effectiveness of the materials were also noted, with one teacher stating, "*It was useful to use the materials provided to work with my students since they were simple and effective*".

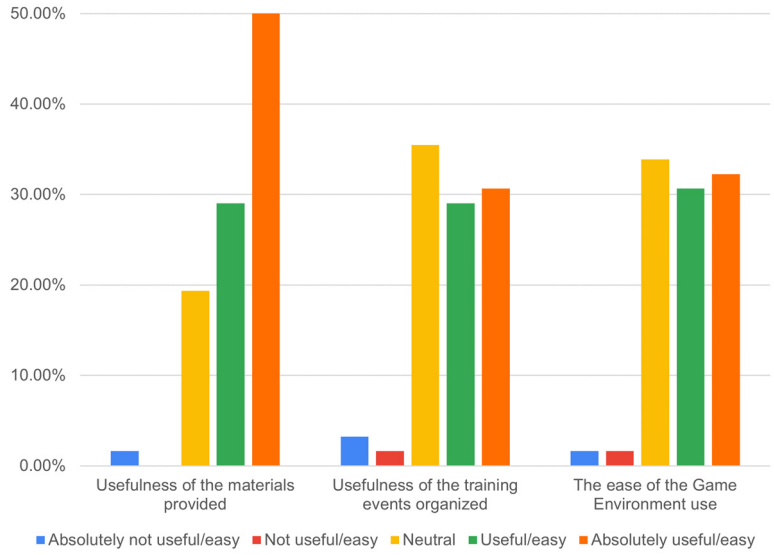

Figure 10. Teachers' perception of the materials, training events, and game environment.

The video-making component received mixed reactions. While it was seen as a significant and engaging task for some students, others found it challenging.

As for the training events organised by the project team, most respondents found them beneficial, with 31% rating them as extremely useful and 29% as useful. The positive feedback emphasised the value of the information provided, the clarification of the project objectives, and the facilitation of idea exchange among teachers. These events helped participants understand and overcome challenges encountered during the project and effectively guided teachers' work with students.

Several teachers found the activities extremely beneficial for their students, as they placed them in concrete learning situations. One respondent mentioned, "*The activities were extremely useful for my students, placing them in concrete learning situations*". Another respondent highlighted the value of the information provided, stating, "*Very useful information*".

The exchange of ideas during the training events was frequently mentioned as a significant benefit. One teacher noted, "*The exchange of ideas is always useful*", while another emphasised, "*Very useful for comparing the difficulties encountered and improving the solutions*". These comments underscore the collaborative nature of the events, allowing teachers to share experiences and find better solutions collectively.

Several respondents appreciated the clarity and additional information provided by the training events. Comments such as "*I became familiar with the purpose and format of the project*" and "*The instructions for working with the students were very clear*" reflect this sentiment. Another teacher stated, "*The training events have been useful to explain some objects of the project*", indicating that the events helped clarify specific project aspects.

However, there were some neutral and negative responses indicating their non-participation in these events. One person mentioned, "*I did not take part in the events*", and another stated, "*We didn't do this at all. So I guess that would have helped a lot*". The responses suggest that, while the training events were helpful for those who attended, there were missed opportunities for others.

To sum up, the training events were seen as a valuable resource for guiding student work, clarifying project objectives, and facilitating the exchange of ideas. Despite some teachers not participating, those who did found the events to be a useful supplement to the materials provided, enhancing their ability to support their students effectively.

The opinions on the ease of use of the game environment varied. While 32% found it "absolutely easy" to use and another 31% found it "easy", a significant portion (34%) remained neutral. A small percentage found it "difficult" (2%) or "absolutely difficult" (1.6%). This mixed feedback suggests that, while a majority found the game environment easy to navigate, there is still room for improvement to address the concerns of those who found it challenging.

Based on the responses provided, the BIG GAME approach is perceived to positively impact students' development of various skills (Figure 11). As can be seen, most respondents have underlined that the BIG GAME approach significantly impacts students' educational paths. It helps students build a strong base for intellectual growth and academic success by teaching important analytical, problem-solving, and critical thinking skills. Additionally, its focus on creative expression and storytelling encourages innovation and helps students understand the importance of narrative in explaining complex concepts. Furthermore, working together in this approach not only improves teamwork and communication abilities but also fosters a sense of community and shared responsibility among students.

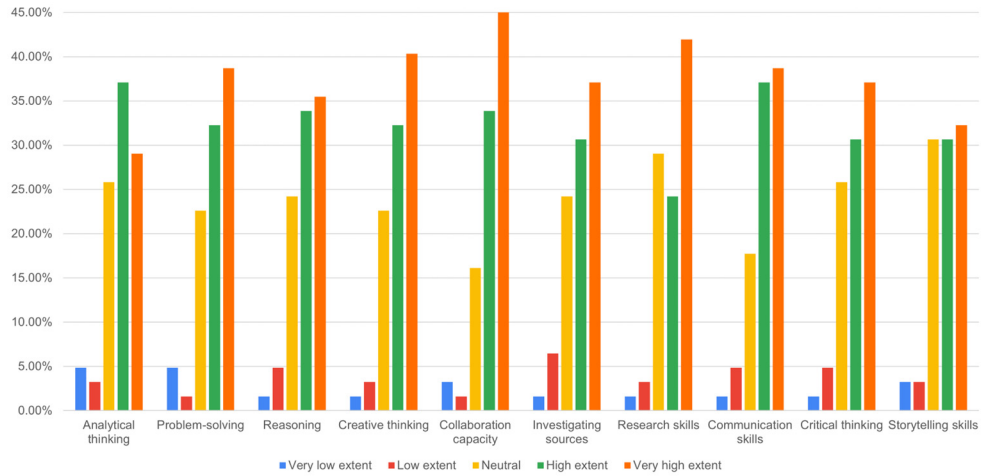

Figure 11. Teachers' opinions on skill development supported by the BIG GAME approach.

Moreover, by encouraging students to explore diverse sources and undertake research, the BIG GAME approach promotes independent enquiry and a thirst for knowledge. This multifaceted approach to skill development equips students with the tools they need to excel academically. It empowers them to shape their learning attitudes and contribute meaningfully and actively to society.

Therefore, the widespread agreement on its effectiveness highlights the BIG GAME approach as a powerful educational force, equipping students with the skills and confidence to tackle future challenges and opportunities.

The results show that the BIG GAME approach has positively influenced students' attitudes towards environmental issues. A combined 80% of respondents either agree or strongly agree that the approach has positively changed their perspectives. Only a small percentage, 4%, disagree with this notion, while 17% remain neutral. This indicates that most respondents perceive the BIG GAME approach as effective in fostering a heightened awareness and concern among students regarding environmental issues, thus reflecting its potential as a catalyst for positive behavioural change and environmental stewardship.

The feedback regarding the strengths of the BIG GAME approach for students reflects a wide range of positive experiences and observations. Many teachers noted the enthusiasm and engagement of their students during the activities, emphasising their active participation, collaboration, and enjoyment. One teacher mentioned, "*The most important thing happened definitely at the lesson, the enthusiasm of my students surprised me. They had good ideas, checked something on the internet from time to time, reasoned, worked together, and really*

had fun solving the Black ice scenario". This highlights the effectiveness of the approach in promoting student motivation and involvement in problem-solving tasks.

Several respondents highlighted the development of critical thinking and collaborative skills as key strengths of the BIG GAME approach. The teachers observed improvements in teamwork, critical thinking, and problem-solving abilities among their students. Additionally, the approach was praised for its ability to stimulate empathy towards nature, cultivate creativity, and encourage students to explore environmental issues in a meaningful way. One teacher noted, "*Strong points—stimulating empathy towards nature, cultivating creativity*", highlighting the positive impact of the approach on empathy and creativity development.

Furthermore, the BIG GAME approach was commended for its interdisciplinary nature and effectiveness in developing a wide range of skills, including analytical thinking, research, communication, and storytelling skills. The teachers appreciated the opportunity for students to work collaboratively, engage in research activities, and think critically about real-world problems. Overall, the feedback indicates that the BIG GAME approach has significant strengths in promoting student engagement, critical thinking, collaboration, and interdisciplinary learning, making it a valuable educational tool for enhancing student learning experiences.

At the same time, the feedback regarding the weaknesses of the BIG GAME approach for students demonstrates a variety of challenges and concerns experienced by teachers. One prominent issue highlighted by several respondents is the significant time investment required to complete the scenarios. The teachers expressed difficulty in fitting the game into their lesson schedules, with one stating, "*It took a lot of time and was kind of difficult to solve. One scenario took about one hour = more than the whole lesson*". Another teacher emphasised the need for different scenarios to maintain student enthusiasm throughout the game, indicating that prolonged engagement with a single scenario could lead to fatigue and disinterest.

Additionally, technical issues related to platform accessibility were reported, including problems with logging in and submitting work. Some teachers also noted that the difficulty level of the problems presented in the game may have been too high for middle school students, leading to boredom and frustration.

However, it is worth noting that not all respondents identified weaknesses in the BIG GAME approach. Some teachers reported positive experiences without encountering any notable drawbacks. One teacher remarked, "*I cannot think of any*", while another mentioned, "*My students had no particular problems*". These responses indicate that the challenges experienced by some teachers may not be universal and could depend on factors such as classroom dynamics and teacher expertise.

As one can see, despite the sufficiently positive feedback praising the BIG GAME approach for boosting student engagement, critical thinking, and collaborative skills, areas remain for improvement. While the method effectively fosters empathy, creativity, and interdisciplinary skills, challenges such as time constraints, task complexity, and technical difficulties were noted. These issues suggest that, while the results are notable, there is still room to enhance the approach further, particularly its effectiveness and usability in educational settings.

5.2. Students' Feedback

After completing the piloting activities, a questionnaire was administered to assess the students' feedback. The enquiries contained demographic information (school, age, and gender) and an assessment of the students' perceptions of their experience, including their preferences for different phases of the activities. Finally, the participants were asked whether they believed their awareness of environmental issues had changed after participating in the BIG GAME project.

The number of respondents to the final questionnaire was 239. The results show that 9% were placed in the 10–11-year-old category, 44% in the 12–13-year-old category, 33% in the 14–15, and 13% were more than 15 years old. Only a small percentage (1,3%)

decided to select "I prefer not to answer". Additionally, the data distribution showed that men and women accounted for 48% of the total, with 4% choosing not to disclose their gender preference.

Based on the comprehensive feedback received (Figure 12), the experience of engaging with the BIG GAME approach varied across different dimensions among the respondents.

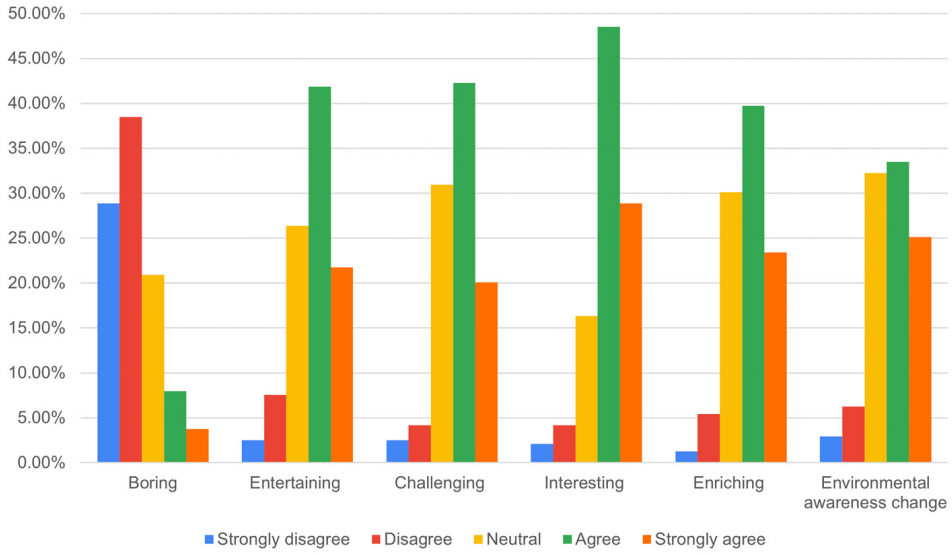

Figure 12. The students' feelings towards the BIG GAME experience.

A significant majority disagreed that the experience was boring (72%), indicating a lack of monotony in the activities, and a substantial portion agreed that it was entertaining (44%), suggesting successful engagement with the content. A notable percentage found the experience "challenging" (45%), indicative of the approach's ability to stimulate critical thinking and problem-solving skills. At the same time, others (11%) perceived it as daunting.

Moreover, most perceived the experience as interesting (79%) and enriching (65%), highlighting the approach's effectiveness in providing engaging and valuable learning opportunities. These insights collectively underscore the multifaceted nature of the BIG GAME approach, which captures participants' interests, challenges them intellectually, and enriches their learning experiences.

The activities most liked by the students encompassed a range of collaborative and problem-solving tasks, including brainstorming, researching, and group work, particularly in the initial phases of the project. The students appreciated the opportunity to engage in hands-on activities such as creating scenarios and filming videos, allowing them to effectively apply their creativity and teamwork skills. In particular, a significant number of the students enjoyed the problem-solving and planning phases, where they had to think creatively about solutions to environmental issues. This phase was particularly engaging for the students, allowing them to use their creativity and critical thinking skills. One student mentioned, "*I liked thinking about the solutions*", while another highlighted, "*My favourite part was when we came up with the solutions to the catastrophe*".

The collaborative aspects of the project were also frequently mentioned as a favourite part. The students appreciated working in groups, which fostered teamwork and cooperation. Many responses, such as "*working in groups*" and "*the group activities*", indicate that the social and collaborative elements of the project were highly valued. This aligns with the educational goals of enhancing students' collaboration skills and peer learning.

Another notable aspect was the video creation phase. The students found the process of making videos both enjoyable and educational. This phase allowed them to apply their knowledge practically and creatively, which was well-received. One student stated, "*The making of the video*", while another said, "*The activity that I liked the most is the realisation of*

the video". This suggests incorporating multimedia elements into educational activities can effectively maintain student engagement.

Lastly, many students highlighted the project's research component as a favourite phase. They enjoyed the investigative nature, allowing them to delve deeper into environmental issues and find relevant information. Comments like "*Research on the net*" and "*Researching*" reflect this sentiment. This phase helped build their research skills and increased their awareness and understanding of environmental challenges.

On the other hand, regarding the insights on the phases the students liked least, analysis has revealed several common themes and preferences among the participants. A notable number of the students disliked tasks involving writing and citing sources. Comments like "*Writing*", "*Citing sources*", and "*Writing in the template's sections*" were frequently mentioned. This suggests that, while students may enjoy the creative and interactive aspects of the project, they find the more technical and detailed documentation tasks less engaging.

Another frequently mentioned phase that students found challenging was the video creation process. Responses such as "filming the video", "Video making", and "*when we recorded the video*" indicate that this task was not as well-received. The reasons could vary from discomfort in front of the camera to the technical difficulties of filming and editing videos. One student noted, "*Definitely when we had to film the video, because I wasn't part of it at all*", highlighting issues with inclusivity or engagement in group activities.

The initial phases of the project also seemed to pose difficulties for some students. Several responses indicated that the first mission or initial planning stages were less favoured, with comments like "*The first phase when we were discussing the subject because it was kind of hard to start from somewhere*". This feedback suggests that more guidance at the beginning of the project might help alleviate some of the initial confusion and make the experience more enjoyable.

Lastly, a subset of the students mentioned that there were no phases they particularly disliked, with responses like "*nothing*", "*none*", and "*I liked all of the parts*". This indicates that, while some tasks were less enjoyable for certain students, the overall project was well-received by many participants. Their positive feedback highlights the project's strengths in engaging students through varied activities, even if certain tasks were challenging.

These findings may suggest that balancing creative and technical tasks, providing clearer instructions, and ensuring all students are actively engaged in group activities to enhance the overall experience are necessary.

Additionally, the students found value in activities that required critical thinking and exploring solutions to environmental problems. Conversely, the activities least favoured were often related to individual tasks, such as writing, recording videos, and synthesising information. Some participants expressed difficulties with specific phases, citing challenges with formulating the final answers and translating content.

The students' opinions regarding whether participation in the BIG GAME project changed awareness towards environmental issues varied. While a small percentage (3%) strongly disagreed or disagreed, the majority either agreed (34%) or strongly agreed (25%) that their awareness had increased (Figure 12).

An analysis of the explanations to the insight reveals a range of perspectives. These can be broadly categorised into increased awareness, unchanged awareness, pre-existing awareness, and ambivalent or unclear responses.

For the first category, a significant number of participants indicated that their awareness of environmental issues had increased as a result of participating in the BIG GAME project. Many students mentioned that they gained new information and a deeper understanding of environmental challenges. For instance, one participant noted, "*This demo game seriously increased my awareness of climate change*", and another stated, "*I now have more information about environmental change*". Some responses highlighted specific areas of newfound knowledge, such as oil crises and environmental destruction, with comments

like "*I know more about oil crisis and environmental destruction*" and "*I learned a lot about what to do to help our planet*".

A subset of the participants felt that their awareness remained largely unchanged. These responses often came from students who already had a high level of awareness about environmental issues prior to the project. For example, one participant mentioned, "*I already knew stuff, and there wasn't much new information*", while another stated, "*My awareness towards environmental issues didn't change too much, but I really liked this project*". This suggests that the project reinforced existing knowledge without significantly altering their understanding.

Several participants indicated that they were already aware of environmental issues before participating in the project. These responses often emphasised a continuous or long-standing concern for the environment. Comments such as "*Global warming was always an important issue for me*" and "*I have always respected the environment*" reflect this sentiment. These participants appreciated the project but did not experience a significant shift in their awareness levels.

It is worth noting that several responses stood out for their detail and representativeness. For example, a participant shared, "*Participating at this Project, I realised that it's important to be more careful at what we do every day and to be aware that even to go to school with the car once a day it's polluting very much our planet and that we can do something to stop this with little things*". Another notable response was, "*My environmental awareness was definitely raised by this project, meaning I will start being more respectful to nature*". These responses illustrate the project's impact on fostering a more conscientious attitude towards everyday actions and their environmental implications.

6. Discussion

The findings from the BIG GAME project underscore the effectiveness of game-based learning methodologies in enhancing student engagement, motivation, and environmental awareness [40,47]. By focusing on environmental challenges, the project aimed to promote increased awareness among the new generation about climate change and its impact on ecosystems and livelihoods worldwide. This approach not only inspires actions to mitigate these impacts but also serves as a dual remedy for the declining interest in STEM subjects while providing valuable opportunities for digital skills acquisition and application [49].

The results indicate that the students who participated in the BIG GAME project exhibited a significant increase in their understanding of environmental issues, aligning with the existing literature that emphasises the positive correlation between the game-based learning environment and improved educational outcomes. One of the key contributions of this project is integrating peer assessment within the learning framework. The structured peer review process facilitated collaborative learning and fostered critical thinking and reflective practices among students. This supports theoretical perspectives that advocate for peer assessment as a means to enhance learning outcomes by encouraging students to engage deeply with the material and each other.

As environmental concerns become increasingly urgent, the relevance of STEM disciplines in tackling sustainability challenges becomes evident due to their multidisciplinary character. The BIG GAME methodology demonstrates the potential of serious games to create immersive learning experiences that resonate with learners. By engaging students in real-world issues and providing them with opportunities to apply digital skills to solve environmental challenges, teachers can foster both interest in STEM subjects and digital literacy, preparing the next generation to address complex global issues effectively.

Moreover, the results reveal that teachers perceived the BIG GAME project as an effective tool for enhancing students' learning experiences. This finding reinforces the theoretical framework that emphasises the importance of teacher facilitation in the game-based learning environment. Teachers played a crucial role in guiding students through the research process, managing group dynamics, and supporting peer assessment, which contributed to a more effective learning environment.

Finally, the BIG GAME project contributes to the theoretical background of game-based learning by providing empirical evidence of its effectiveness in promoting engagement, collaboration, and critical thinking. Integrating peer assessment within this framework enhances learning outcomes and aligns with contemporary educational theories that advocate for active, student-centred learning approaches. The environmental context of the project serves as a consolidating catalyst for the tools chosen, aiming at both STEM and soft skills acquisition and development, ultimately revitalising STEM education and fostering environmental awareness among students.

7. Conclusions

The COVID-19 pandemic has worsened the decline in interest and learning outcomes in science subjects across Europe, emphasising the urgent need to strengthen STEM and digital education globally. This decline poses significant challenges for future workforce development and societal progress, given STEM's vital role in promoting innovation and economic growth.

The BIG GAME project has shown promise as a valuable tool for teachers, particularly those focused on STEM subjects. With an emphasis on collaboration, problem-solving, and critical thinking, the project aligns closely with STEM education goals and offers adaptable materials suitable for various topics. Despite minor challenges, such as time constraints and technical issues, BIG GAME has the potential to provide an engaging platform for teaching students about environmental issues and other relevant subjects.

Participation in BIG GAME significantly enhances students' awareness and understanding of environmental issues. The project's interactive, game-based learning approach allows students to connect theoretical knowledge with real-world applications, fostering a deeper emotional connection to the material and motivating them to take action. By focusing on local and global environmental challenges, the project valorises the learning experience, making issues more immediate and impactful and enhancing students' sense of agency in addressing these challenges.

Students find collaborative activities involving critical thinking and problem-solving the most engaging, highlighting the importance of social interaction in educational settings. These activities encourage teamwork and creativity, essential for effective learning, while individual tasks, such as writing research reports or synthesising information, present challenges that indicate a need for structured guidance. As the teachers' feedback reveals, BIG GAME enhances student engagement and fosters environmental awareness, cultivating critical skills like teamwork, problem-solving, and scientific reasoning.

However, this study has limitations, such as a sample size that may not fully represent the broader student population across Europe, potentially affecting the generalizability of the findings. Additionally, this study's short duration means that the long-term effects on students' knowledge of and attitudes towards environmental issues were not evaluated. Future research should explore a wider range of educational interventions and include larger, more representative samples to validate and expand upon these findings, considering longitudinal studies. Nevertheless, the BIG GAME project methodology leverages feedback for continuous improvement, using insights from surveys to refine its approach and enhance its effectiveness in educational settings and eventual future implementations.

In conclusion, BIG GAME demonstrates the potential of game-based learning to address challenges in STEM education. It provides a transformative educational approach by connecting academic content with social and ethical considerations, leading to meaningful learning outcomes and fostering a more environmentally conscious and proactive student attitude. The project underscores the importance of innovative educational practices and strategies in developing engaged and motivated STEM learners.

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