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Special issue
Board and video games in education: challenges and opportunities

Guest Editors
Marcello Passarelli, Massimiliano Andreoletti, Lilina Silva, Sylvester Arnab

Italian Journal of Educational Technology

ISTITUTO TECNOLOGIE DIDATTICHE

Dear readers,

starting from this issue – the first of 2025 – I am taking on the role of Direttrice Responsabile of the *Italian Journal of Educational Technology*. It is a responsibility that deeply honors me, also representing an extraordinary opportunity for my professional growth.

Having worked for many years as a science journalist for the National Research Council of Italy (Cnr), the chance to become more directly involved in the work of a research community of one if its Institutes allows me, once again, to broaden my perspective in understanding its goals, achievements and values, pushing me to the very frontier of knowledge in this crucial field, which is currently undergoing deep transformations.

For this reason, one of my first tasks will be to help increasing the visibility of the Journal as widely as possible, promoting and showcasing its many contributions – along with calls for papers as well as every milestone of its "ongoing life" – to a broad range of stakeholders: academics, Italian and international research institutions, policymakers, educational system, mass media.

The *Italian Journal of Educational Technology* is the first Italian scientific journal dedicated to educational technologies, and certainly one of the longest-standing journals of the Cnr. In my vision, it will be important to preserve its uniqueness and prestige, giving evidence to the reflections it offers, and sharing them with broader segments of society with the goal of fostering an informed and conscious public debate. The evolution of educational technologies and their impact on the educational system is, also, a topic that personally involves me, having dedicated part of my research job in exploring which skills are essential to preserve and develop in order to interact appropriately with AI – a tool which is becoming increasingly pervasive even in teaching and educational contexts.

For my part, I will be fully committed and responsible in supporting the work of the Editor-in-chief, the Co-editors, and the Editorial Board, to ensure that the Journal continues to serve as a key reference point and an "open laboratory" around these topics.

Enjoy your reading, and may we walk this path together.

Francesca Gorini

Cari lettori,

da questo primo numero del 2025 assumo l'incarico di direttore responsabile dell'Italian Journal of Educational Technology. È un compito che mi onora, e che rappresenta per me una straordinaria opportunità di crescita professionale: operando da anni al servizio dell'Ente come giornalista scientifica, avere la possibilità di entrare nel vivo del lavoro di una comunità di ricerca mi permette di allargare ancora una volta lo sguardo nel comprenderne gli obiettivi, i traguardi, i valori, spingendomi alla frontiera della conoscenza di questo settore cruciale, oggi al centro di profonde trasformazioni.

Per questo, penso che uno dei miei primi compiti sia quello di contribuire a far conoscere al più ampio raggio possibile la rivista, diffondendo e valorizzando presso gruppi di interesse molteplici – accademici, organismi di ricerca italiani e stranieri, mondo istituzionale, sistema educativo, mondo dell'informazione – i tanti contributi che questa rivista riunisce, così come le call for papers e tutti i momenti salienti che animano la "vita" della rivista.

L'Italian Journal of Educational Technology è la prima rivista scientifica italiana dedicata all'ambito delle tecnologie educative, e certamente una delle più longeve del Consiglio nazionale delle ricerche: nella mia visione, sarà importante salvaguardarne l'unicità e il prestigio, dando risalto ai tanti spunti di riflessione che essa offre, e condividendoli con larghe parti della società, anche con l'obiettivo di favorire un dibattito il più possibile informato e consapevole. L'evoluzione delle tecnologie educative e il loro impatto nel sistema formativo è, infatti, un tema che mi ha coinvolta in prima persona anche attraverso articoli e contributi a convegno, in un lavoro di ricerca nel quale ho indagato, in particolare, quali competenze sia importante preservare e sviluppare per interagire in modo corretto con l'AI, strumento oggi entrato prepotentemente anche in ambito scolastico e didattico.

Da parte mia, garantirò pertanto il massimo impegno e responsabilità nel coadiuvare il lavoro del Direttore Scientifico, dei Co-editors e del Board editoriale affinchè la rivista possa confermarsi quale un punto di riferimento e "laboratorio aperto" sul tema.

Buona lettura, e buon cammino insieme.

Francesca Gorini

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Editorial. Board and video games in education: Challenges and opportunities

Editoriale. Giochi da tavolo e videogiochi nell'educazione: Sfide e opportunità

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ABSTRACT Game-Based Learning (GBL) continues to gain traction across educational levels, offering engaging, experiential approaches that foster both disciplinary learning and transversal competences. The articles featured in this special issue explore the educational potential of both commercial and serious games, digital and analog, to support learning in diverse domains, from STEM to media literacy. The issue also addresses key challenges in GBL implementation, including the need for learning design skills, teacher training, and inclusive practices that respond to learner diversity. Contributions adopt a variety of methodologies, from experimental studies to critical reviews, and extend the field's scope by investigating underexplored topics such as biofeedback-based games and gender-related differences in gamification effectiveness. Taken together, the contributions emphasize the sheer variety of GBL approaches, while carefully considering how GBL should be employed to be effective.

KEYWORDS Game-Based Learning (GBL); Transversal Skills; Board Games; Video Games; Teacher Training.

SOMMARIO Il Game-Based Learning (GBL) è sempre più popolare in tutti i livelli scolari, offrendo approcci coinvolgenti ed esperienziali che promuovono l'apprendimento disciplinare e le competenze trasversali. Questa special issue esplora il potenziale educativo dei giochi commerciali e dei "serious games", in formato digitale e analogico, a supporto dell'apprendimento in diversi ambiti, dalle STEM alla media literacy. Il numero esamina le difficoltà legate all'implementazione del GBL, come la necessità di competenze nella progettazione didattica, di formazione degli insegnanti e di pratiche inclusive che rispondano alla diversità degli studenti. I contributi adottano una varietà di metodologie, da studi sperimentali a rassegne della letteratura, ed estendono il campo d'indagine esplorando temi poco trattati, come i giochi basati sul biofeedback o le differenze di genere nell'efficacia della gamification. Nel complesso, i contributi mettono in evidenza la varietà degli approcci al GBL, riflettendo su come il gioco debba essere impiegato per risultare davvero efficace.

PAROLE CHIAVE Game-Based Learning (GBL); Abilità Trasversali; Giochi da Tavolo; Videogiochi; Formazione Docenti.

1. Editorial

Game-based learning (GBL) has gained considerable traction in education, offering engaging and motivating experiences that promote active, experiential learning. Unlike traditional frontal instruction, GBL provides learners with meaningful contexts to develop both disciplinary knowledge and complex skills. This aligns with the recommendations of constructivist pedagogies to foster deeper, longer-lasting retention (Plass, Homer, & Kinzer, 2015; Rye, Sousa, & Sousa, 2025). In addition to its benefits for subject-specific learning, GBL is increasingly seen as a promising approach for promoting transversal and 21st century skills such as creativity, collaboration, critical thinking, and problem solving (Arnab & Walaszczyk, 2022; Arnab et al., 2021; Bermingham et al., 2013). While game- and play-based approaches have historically been associated with childhood education, we now see GBL interventions extending across all school levels and even to online and hybrid learning contexts (Silva, 2021).

Still, GBL faces several challenges. First, using games as learning tools requires careful design of the educational activity as well as familiarity with the medium of games (Passarelli et al., 2019). Second, teacher adoption remains uneven; for instance, research indicates relatively low acceptance among Italian teachers (Andreoletti, Tinterri, & Dipace, 2024). Importantly, practical constraints in terms of time, learning spaces, and school resources can make teachers apprehensive about trying GBL approaches in the classroom.

Another important aspect is the disproportionate academic attention given to digital games when compared to other game types, such as board games (Hwang & Chen, 2022). This point is especially relevant for this special issue. In 2019, the Italian Journal of Educational Technology published a special issue on digital games and learning (Dagnino, Passarelli, Perrotta, & Persico, 2019). The contributions to that issue were already quite varied in terms of the type of games used, from immersive virtual reality games to gamified stress-management apps. Yet, the call for papers for that issue limited the scope to games with a digital component. Since then, we have observed a resurgence of tabletop games in popular culture, as well as a growing number of games mixing digital and analog components. This special issue aims to expand the focus of the previous one, exploring how both digital and non-digital games are being experimented and applied in formal educational contexts.

The special issue was conceived by the INSERT COIN commission of the Game Science Research Center (GSRC), an interdisciplinary group that connects Italian researchers and practitioners interested in understanding games and their impacts on all aspects of society, including learning. We are also grateful that one of our guest editors, Professor Sylvester Arnab from Coventry University (UK), could join us in this endeavor, so that the growing interest for game science in Italy could be more effectively linked to the wider efforts in the international research environment.

In selecting contributions, we aimed for diversity in game formats, research approaches, learning objectives, and learner populations. The six articles in this issue thus vary in their use of video games, board, and card games, repurposed commercial games, and gamified activities; yet, they share a common goal: to harness the potential of games for making learning experiences more engaging, effective, meaningful, and inclusive.

The issue is opened by a study from Toniolo, Inchingolo, Zanazzi, and Casu, focusing on GBL for STEM education. The study presents "COSMO HUNTERS," an analog card-based game designed to support middle-school students' learning of concepts related to the electromagnetic spectrum and astrophysics. In a quasi-experimental intervention the authors showed that, compared with a tradi-

tional approach, playing COSMO HUNTERS led to better retention after four weeks and a marked increase in student enjoyment. This study opens the issue by putting the spotlight on analog games' potential for learning, widening the focus when compared to the 2019 IJET special issue.

The second contribution, by Carenzio, Pasta, Contreras-Espinosa, Eguia-Gomez, Tymoshchuk, Antunes, Passos, and Proença presents multiple serious games for fostering the transversal skill of media literacy. The authors present the YO-MEDIA project, which entailed the design of two board games ("Social Media Puppeteers" and "Social Media Fake News") and a videogame ("Data Defenders"), all designed to promote media literacy among secondary school students. By engaging players in the production, deconstruction, and verification of information, these games introduce "pre-bunking" and "debunking" strategies. This contribution exemplifies how both tabletop and digital designs can be used not only for disciplinary learning, but also to successfully promote complex skills and competences beyond childhood education.

The third article, by Della Rocca, Scrocco, Pecini, Tarchi, and Bombonato also focuses on media literacy, but through the lens of reading comprehension and critical engagement with multiple texts. In their experimental study with the videogame "Elli's World," students in Grades 5 through 7 showed performance improvements in media literacy tasks over successive gameplay sessions. The study highlights potential drawbacks of GBL approaches, such as the possibility of fatiguing players after multiple playing sessions, and better rates of improvement for younger rather than older students. Critically, the study highlights that although teachers reported moderate satisfaction with the approach, they observed no changes in students' behavior. Therefore, this study represents a more critical voice within the issue when it comes to games for learning, which examines their effectiveness without shying away from considering potential drawbacks.

The fourth contribution, by Di Leo and Traetta, offers a review of the use of Minecraft, a commercial game that has long been integrated into educational settings within both early years and secondary classrooms. Unlike the other studies, this review examines the adoption of an off-the-shelf game and its repurposing as an educational tool, a markedly different approach from designing games from the ground up as purpose-built educational experiences. The authors' systematic review finds consistent evidence that Minecraft fosters spatial thinking, creativity, and engagement. Yet the authors emphasise that without teacher training and robust assessment frameworks, the potential benefits of such educational interventions often go unrealized. This underscores a recurrent message throughout this special issue: the need for educators to cultivate the requisite pedagogical design skills to optimally integrate the playful elements of popular games like Minecraft.

The fifth contribution, by Richter and Kickmeier-Rust, is a gender-focused exploration of gamification in the "Basketball Physics Challenge". Again, this study focuses on a different approach from the others, as gamification is the adoption and use of game elements in an environment that does not constitute a full-fledged game (Deterding, Dixon, Khaled, & Nacke, 2011). Importantly, the study highlights a critical issue of gameful approaches, that is, how they typically seem to engage males more than females. This crossover study, which involved secondary students, addresses the critical concern that using GBL for STEM teaching might inadvertently widen the gender gap. While it found no significant gender differences in overall performance, it did reveal distinct patterns in motivation and engagement. In particular, girls reported high engagement initially, which declined under gamified conditions, whereas boys showed a slight uptick in motivation. These findings serve as a reminder that "one-size-fits-all" solutions in game-based learning may fail to account for nuanced learner differences, and this approach should always be mindful of the learning context.

The closing article of the issue is a review on biofeedback-based games by Mercer and De Franches. This review maps a research domain more typically explored in therapeutic contexts, where such games serve as tools for emotional regulation and cognitive enhancement, and proposes extending biofeedback into teacher training. Adopting a critical disability studies lens, the authors argue that biofeedback mechanics can strengthen teachers' emotional well-being and reduce burnout. Their paper presents an uncommon, innovative, and promising game technology while stressing the importance of applying games not just to student education but also for directly supporting teachers in facing the complex demands of their job. We chose to close the issue with this forward-looking paper, as its unconventional approach suggests that many potential applications of games are yet unexplored.

We hope the articles in this issue inspire researchers and practitioners to further explore how best to leverage games for learning, while considering all game modalities and the wide variety of learning applications. We also encourage educators to further experiment with both analog and digital games, collaborate closely with researchers to measure impact, and share best practices for scaling GBL approaches in real classrooms.

Designing effective game-based interventions remains a challenging endeavor, requiring careful orchestration of learning goals, learners' tasks, personalization, and adaptation to the specific context, as well as ongoing reflections on learners' experiences. However, this special issue reaffirms that board and video games alike can foster learners' motivation and engagement, critical thinking, well-being, and disciplinary learning – making the learning design effort worthwhile.

2. Acknowledgements

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ISTITUTO TECNOLOGIE DIDATTICHE

Cosmo Hunters – a card game for middle-school (K12) Astronomy Education

Cosmo Hunters – gioco di carte per la didattica dell'astronomia nelle scuole secondarie di secondo grado

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ABSTRACT We explored the potential of the original card game Cosmo Hunters to engage low secondary school students and promote interest in astrophysical observations and the electromagnetic spectrum. We involved 175 Italian 13-years-old students and compared a game-based learning activity that used Cosmo Hunters with a frontal lesson with the same content. We tested the interest in the addressed scientific aspects before starting the activity, immediately after, and four weeks later. Overall, we concluded that our game-based learning approach is enjoyable and engaging. We also noticed that it enhances more efficiently the interest in the scientific aspects embedded in its game mechanics, i.e., the existence of different frequencies of the electromagnetic spectrum and the multi-frequencies observations used in astronomical research. We concluded that Cosmo Hunters can offer a compelling alternative to standard lectures for introducing and engaging the students with the basic concept of the electromagnetic spectrum and astrophysics observations.

KEYWORDS Game-Based Learning; Light; Astrophysics; Middle Schools; Card Game.

SOMMARIO Questo studio esplora il potenziale del gioco di carte Cosmo Hunters nel coinvolgere studenti e studentesse delle scuole secondarie di primo grado e promuovere l'interesse in merito ai temi delle osservazioni astrofisiche e dello spettro elettromagnetico. L'analisi ha coinvolto 175 studenti italiani di 13 anni e ha messo a confronto un'attività di didattica ludica basata su Cosmo Hunters e una lezione frontale con gli stessi contenuti. La valutazione dell'interesse è stata svolta prima di iniziare l'attività, alla fine e dopo quattro settimane. Si evince che l'approccio ludico è più coinvolgente, nonché favorisce l'interesse per gli aspetti scientifici incorporati nelle meccaniche del gioco, ovvero l'esistenza di diverse frequenze dello spettro elettromagnetico e le osservazioni multifrequenza utilizzate nella ricerca astrofisica. Si conclude che Cosmo Hunters è una valida alternativa per introdurre e coinvolgere studenti e studentesse in merito ai concetti base sullo spettro elettromagnetico e sulle osservazioni astrofisiche.

PAROLE CHIAVE Apprendimento Ludico; Luce; Astrofisica; Scuole Secondarie di Primo Grado; Gioco di Carte.

1. Introduction

The rising discipline of game studies has proven several times the effectiveness of board and digital games in promoting learning (Nesti, 2017). Indeed, they have the potential to create positive and enjoyable learning environments that can:

- offer a safe space – known as "magic circle" (Huizinga, 1949) – separated from daily life reality (Callois, 2001), which encourages free and creative experimentation;
- enhance motivation to learn (Bayeck 2020) by reaching a "state of flow" where players perceive themselves as able to overcome all the obstacles and challenges (Csikszentmihalyi et al., 2014);
- promote a learning-by-doing approach through active participation (Illingworth, 2019).

Research suggests that learning outcomes can be reached more effectively through game mechanics rather than the content alone (Bayeck, 2020; Yoon & Khambari, 2022). In particular, Andreoletti and Tinterri (2023) emphasized that the simulation of the aspects of a real system in a game helps players develop knowledge about how that system works. On the other side, while games that display explicit educational content are effective tools to reinforce learning (Cardinot & Fairfield, 2022), there is a risk of losing their appeal and, therefore, students' motivation and engagement, becoming "serious games" (Deterding et al., 2011). The intrinsic voluntariness that characterised games – as pointed out by Caillois (2001) – is then sacrificed when implementing a game in an educational context. Therefore, educational games must be carefully designed to maintain engagement (Ligabue, 2023).

To address this challenge, the first approach is to design tailored board games for game-based learning (GBL) activities to promote engaging science education. This approach is preferable for conveying complex scientific topics (Cardinot et al., 2022) but requires expertise in game design to create an engaging board game properly. For example, "Diamond: The Game" aims to promote scientific careers and experiences in secondary school students (Murray et al., 2022); "PIXEL – Picture of The Universe" makes players experience the processes and dynamics behind astrophysical research (Inchingolo et al., 2023; Toniolo et al., 2023); Cardinot and Fairfield (2022) developed a board game to enhance students' knowledge of astronomy concepts and perceptions of scientists; "Catan: Global Warming" is an expansion of a well-known commercial board game in which the game mechanics promote dialogue around global warming (Illingworth, 2019).

Another approach is to use commercial board games to create tailored GBL activities. In Inchingolo et al. (2024), we proposed an analysis of a ludography for space and astronomy education activities. We found a selection of board games that can be used for educational activities in middle and high school ages. However, the duration and complexity of some commercial board games require a tailored adaptation of these games when used in a school environment.

Despite the chosen approach with either commercial or novel board games, teachers and educators might face different challenges in designing GBL activities.

Choosing or developing a proper game requires high game media literacy (Swertz, 2019) and familiarity with games (Ligabue, 2023) to identify a suitable match for the activity. At first glance, most board game rules can appear confusing and hard to understand, and the number of rules can prevent a newbie gamer from enrolling in a game.

This factor also includes students, many of whom are not used to playing board games and, therefore, are not used to listening and understanding the rules quickly and keeping their attention on the activity (Ligabue, 2023).

The second challenge is the significant effort required from teachers/educators to prepare and implement the activity. Andreoletti and Tinterri (2023) summarized the various roles teachers can take

on in GBL activities: player, instructor, guide, observer, director, assistant, initiator, referee, game character, subject matter expert, evaluator. All these roles unfold before, during, and after the activity itself, creating additional workload, which can prevent teachers from enrolling in such activities due to the high effort needed.

Moreover, Marklund et al. (2016) emphasised the need for contextualisation and a structured format to ensure that the playful activity achieves its educational goals, which further increases the preparation effort.

The third challenge involves time constraints within the classroom. The analysis paper of Inchingolo et al. (2024) showed that most of the astrophysics-themed board games on the market have a gameplay duration ranging from 60 to 120 minutes. This duration, added to the time needed to explain the rules and to do the educational debriefing after the play, makes it more challenging to fit GBL activities in educational sessions, which in Italian schools usually last up to of 100 minutes.

These challenges pushed us to develop and implement Cosmo Hunters, a card game that requires little or no familiarity with board games and has a gameplay lasting 20 minutes.

It aims to introduce, through game mechanics, the topic of astronomical observations of celestial objects at different frequencies of the electromagnetic spectrum with upper primary and middle school students (10-14 years old).

After the development, we tested the playability of Cosmo Hunters in different contexts with over 500 students aged 8 to 16, and we ended with the final version. In this study, we aim to test its potential to engage 13-year-old students and function as an educational tool to promote interest in the topic addressed right after the activity and four weeks later. To verify this, we compared our GBL activity using Cosmo Hunters with a frontal lecture covering the same educational topics of the game, involving 175 Italian students.

The paper is structured as follows. Section 2 provides a detailed description of the board game Cosmo Hunters. The methods used to conduct the analysis are described in section 3. The results are presented in section 4 and discussed in 5, while the conclusions are drawn in section 6.

2. Cosmo Hunters

In this section, we present Cosmo Hunters, the card game we developed for our GBL activity and the educational scientific messages we want to empower with this GBL activity.

Cosmo Hunters[1] is a card game for 2 to 6 players (up to 8 in pairs in educational activities) for people of 8+ years old; gameplay lasts 20-30 minutes. The game was developed by Giannandrea Inchingolo in collaboration with National Institute for Astrophysics (INAF) – Arcetri Astrophysical Observatory and GAME Science Research Center.

The game is used in GBL activities to introduce and discuss the basic concept of the electromagnetic spectrum and how astrophysics observations exploit it to study celestial objects with upper primary and low secondary school students (10+ years old).

The game was developed keeping in mind the three main challenges teachers face when implementing GBL activities in their classrooms, i.e., the game media literacy required to easily understand and explain/play new game rules, the effort to implement a GBL activity connected to this game, and the time constraint.

[1] Full description available here: https://play.inaf.it/en/cosmo-hunters-en/

Figure 1. One Ultraviolet Observation card, one Infrared Telescope card and one Infrared Observation card. In this configuration, the player scores only 3 points on the Infrared Observation card because there isn't an Ultraviolet Telescope card.

In particular, to help educators use Cosmo Hunters for the GBL activities, we developed a guide for educators/teachers that will be provided together with the online free print version of the game. The guide is a collection of tips we collected in the various activities (including the ones for this study), additional material to use for the debriefing phase and a timeline to structure the activity.

The game mainly includes two types of cards, Observation cards and Telescope cards, divided into six frequency categories: Radio, Infrared, Visible, Ultraviolet, X-rays, Gamma rays. A third type is the Event cards, which introduce some variability in the game. The goal is to collect several Observation cards combined with the proper frequency Telescope card to score points and win. Each card in the game is associated with authentic astrophysics images of astrophysical objects and telescopes, making the setting even more evocative and deepening the scientific information on the cards.

Each Observation card represents a celestial object observed at a specific frequency of the electromagnetic spectrum. Players score points with the Observation cards if they have at least one Telescope card of the same category, as seen in Figure 1.

This mechanic mimics a basic mechanism in astrophysics research: to observe a celestial object, astrophysicists need an instrument (a telescope), which, however, is not sensible to all the frequencies of the electromagnetic spectrum. Therefore, they need specific telescopes for each observational band. The Telescope cards present the various types of telescopes currently used in contemporary astrophysics, showing that telescopes are much more varied in type than the common idea, e.g. the classic Galilean tube telescope on a tripod.

In addition, two sets of three Observation cards – characterised by a symbol – give extra points if collected together. They represent the same celestial object observed at different frequencies (Radio, Infrared, Ultraviolet and X-rays). See Figure 2 for an example.

Figure 2. Centaurus-A Galaxy Observation card in three different frequencies: Infrared, Radio and X-rays. All together, with their corresponding Telescope cards, are worth 15 points instead of 9.

Table 1. How the game mechanics we designed are linked with specific scientific aspects.

Scientific Aspects (SA)	Game mechanic
SA1. There are different kinds of light [frequencies of the electromagnetic spectrum] emitted by objects.	There are different kinds of Observation cards, each representing an electromagnetic frequency emission.
SA2. Different kinds of telescopes are used to observe celestial objects.	For every electromagnetic frequency emission, there is a corresponding Telescope card.
SA3. The same celestial object can emit different kinds of radiation at the same time.	Extra points can be earned if Observation cards of the same celestial object at different frequencies are collected.

This mechanic reproduces the astrophysics concept of multi-frequencies analysis: to properly understand the physics processes ongoing on a specific celestial object, astrophysicists often need to observe and study it at different frequencies of the electromagnetic spectrum, as each emitted frequency is produced by a particular process.

Table 1 summarizes the main scientific aspects introduced by the game through game mechanics.

3. Method

This study tests the potential of Cosmo Hunters to engage 13-year-old students in educational contexts and promote interest in the scientific aspects addressed and reported in Table 1.

We conveniently sampled 175 students in the last year of an Italian low secondary school (around 13 years old) in the city centre of Florence, in an area that is not too wealthy nor disadvantaged, with a certain number of students coming from immigrant families (around 12%).

Table 2. Compositions of the groups.

	Lesson group	Game group
Female	40	53
Male	36	46
Total	76	99

Figure 3. Timeline of the activity sessions conducted during spring 2024.

The decision to limit our study to 13-year-olds was made considering the Italian school curriculum, where the topic of light is briefly introduced at that age but still not deeply explored. Moreover, this target age is one of the more at risk for school drop-out, as reported by the report of the Italian Ministry of Education[2]. With our intervention, we aimed to involve students who are in a critical stage of their educational lives, in which they need to choose which high school is best for them.

We divided the students into two groups (Lesson and Game), as reported in Table 2.

We delivered a two-hour intervention to each group, as represented in Figure 3. For the Game Group, we delivered a GBL activity using Cosmo Hunters, followed by a debriefing session. For the Lesson Group, we delivered a frontal lecture with the same educational content conveyed by the game. For both groups, we administered a pre-test before starting the activity, a post-test at the end of it, and a follow-up test four weeks later.

The activities (GBL and frontal lecture) lasted 1.5 hours.

To the Game Group, we delivered a GBL activity that included gameplays of Cosmo Hunters, followed by a debriefing session of 45 minutes.

[2] https://www.foe.it/files/2024/01/Focus-La-Dispersione-scolastica-aa.ss_.1920_2021-2021_2122.pdf

Table 3. List of questions presented in different tests (third column). The second column indicates the scientific aspects (SA) connected to this question in the game mechanics.

Question	Connected scientific aspect	Test
Q1: Recognise daily life objects that emit light [multiple-choice]	SA1	Pre and follow-up
Q2: List the types of light known [open-ended]	SA1	Pre, post, and follow-up
Q3: Identification of different kinds of telescopes [multiple-choice]	SA2	Pre, post, and follow-up
Q4: Identification of multifrequency astronomical observation [single-choice]	SA3	Pre, post, and follow-up

The students were divided into groups of 8 and played in pairs. This approach is effective in preventing students from feeling intimidated when playing the game for the first time and fostering the exchange of ideas and strategies, leading to a deeper processing and understanding of the topics (Ligabue, 2023).

The aim of the debriefing session is to reinforce the knowledge conveyed by the game, fostering the discussion between the students. In that part, the role of the facilitators is just to ask some questions related to the game to start the dialogue, guiding students to find the answers by themselves. See the Appendix for the questions used in this study.

The Lesson Group attended a frontal lecture delivered by astrophysics communication experts, presenting the same content introduced by Cosmo Hunters. Moreover, the images embedded in the lecture were the same as the game cards. The details of the lecture are reported in the Appendix.

It's clear that even if the lecture covered the same topics as Cosmo Hunters, the one-hour lesson allowed us to go deeper into the details of the topics with respect to the GBL activity within the same timespan.

The aim of the pre-test was to assess the students' previous knowledge of the electromagnetic spectrum and astrophysics observation. By comparing its answers with the ones of the post-test (delivered at the end of the intervention), we claim to evaluate whether the interest in the scientific topic addressed in the activity was raised in the students. This is demonstrated by the fact that they paid attention and therefore answered correctly to the questions. Furthermore, we assessed the long-term impact by delivering a follow-up test four weeks after the intervention. Answering each questionnaire took the students around 15 minutes.

Table 3 summarises the four main questions of the three questionnaires, which represent the source of data for this study. See the Appendix for a detailed description.

To design the evaluation tools of the pre-, post- and follow-up questionnaires and to design a correct debriefing part for the GBL activity, we involved a control group of 43 students of the same target age (13 years old) to implement their feedback in the final design of the educational and evaluation tools.

4. Results

In this section, we present the results of the pre, post, and follow-up questionnaires.

4.1. Engagement

In the post-test, we asked students about their perceived enjoyment of the activity. In Figure 4, we show the distribution of a Likert scale evaluation. The lower value (1) means "not at all enjoyed", while the higher one (7) means "very much enjoyed".

Figure 4. Answers to the question: "On a scale from 1 (not at all) to 7 (very much), how much did you enjoy the activity?".

We can observe that for the Game Group, the distribution has an average enjoyment of 6.0/7 and more than 75% of students replied with high enjoyment values between 6 and 7. On the other hand, the lesson group had a lower average enjoyment value (5.3/7) with more than 80% of replies between 5 and 6, and less than 4% replied "very much enjoyed" (7).

We can conclude that the game activity was more engaging than the lesson activity, and students engaged more with the game than the lesson, activating more emotional memory while doing the GBL activity.

4.2. Interest in the scientific aspects

We tested the efficacy of Cosmo Hunters as an educational tool to stimulate interest in the topic addressed by the game. To do so, we asked students to answer the four main questions reported hereafter (see the Appendix for further details).

- **Q1.** Recognize daily life objects that emit light. Multiple-choice between a series of 10 images. Only five are the correct answers.
- **Q2.** List the types of light they know [open-ended].
  In the pre-test, this question was formulated in relation to Q1, i.e., "Specify what type of light the selected objects emit"
- **Q3.** Recognize which instruments are telescopes.
  Multiple-choice between a series of 10 images. Only five are correct.
- **Q4.** Identification of multifrequency astrophysics observation.
  The question displays three images of the same celestial object seen through different frequencies. The answer is a single choice between four options.

The images of the objects of Q1 were chosen accordingly to establish literature on students' misconceptions about light and vision, e.g., the eye and mirror are often thought to emit light, as reported by (Besson, 2015).

Q1 and Q2 address the topic of the existence of different frequencies of the electromagnetic spectrum emitted by objects. The Game Group had the chance to experience it through the different types of fre-

quencies depicted in the cards (Q2). These contents were also included in the lecture delivered to the Lesson Group. Moreover, during the debriefing of both groups, we fostered reflection about how some daily life objects can emit different frequencies (Q1) using the same images displayed in the questionnaire.

The goal of Q3 was to assess whether or not students paid attention to the images of the telescopes presented through the Telescope cards of the game, or during the lecture. In a similar way, Q4 tested if students truly understood the game mechanics related to multi-frequency observation. Indeed, the images presented in the test were those shown and discussed during the lecture and represented in the cards of the game.

Responses have been analyzed using multiple regression (for questions with a numerical score, i.e., Q1 and Q3) or logistic multiple regression (for questions with a single correct answer, i.e., Q4).

For Q1 and Q3, a value of 1 was assigned to each correct item that was selected and to each incorrect item that was not selected, while a value of 0 was assigned otherwise (the maximum score was 10). We summed up the values for every student and used these results to calculate the estimated marginal mean of scores using multiple regression analysis.

On the other hand, for Q4, we assigned a value of 1 when the correct response was selected and 0 to the other ones. The results were used to calculate the predicted probability of group scores using the multiple regression analysis.

Since Q2 is an open-ended question, we decided to calculate the percentage of correct or partially correct answers. We highlighted the presence of keywords of the electromagnetic spectrum, such as "radio", "infrared", "visible", "ultraviolet", "x-rays", and "gamma rays". We consider an answer correct or partially correct if it at least presents one of these highlights. Answers listing known other of light, e.g. "natural/artificial light", "thermic light", "led", etc., were considered wrong.

The results of each analysis are reported hereafter.

Figure 5 shows the evolution of the estimated marginal mean of scores between the pre-test and follow-up of questions Q1. In the pre-test, it's 7.08 with a standard error (SE) of 0.16 for the Game Group and 6.98 with SE of 0.18 for the Lesson Group, while in the follow-up it's 8.38 with SE of 0.16 and 8.38 with SE of 0.18, respectively.

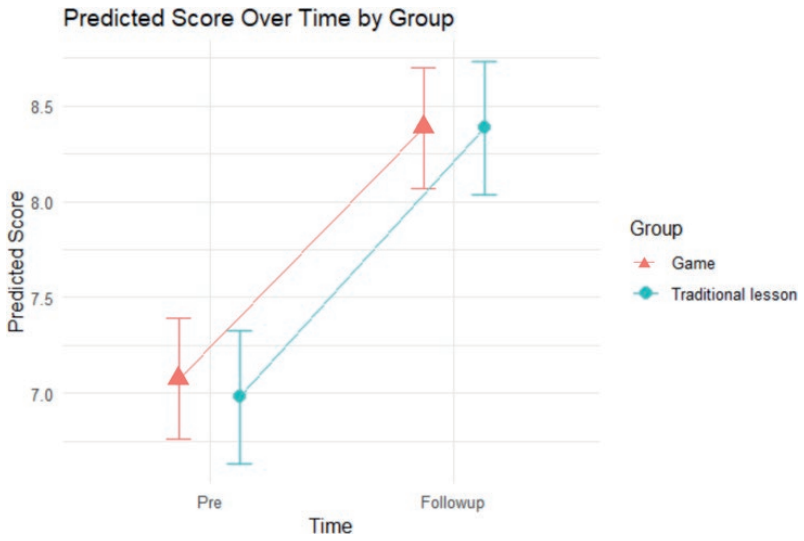

Figure 5. Predicted score over time of question Q1: "Which of these objects emit light?".

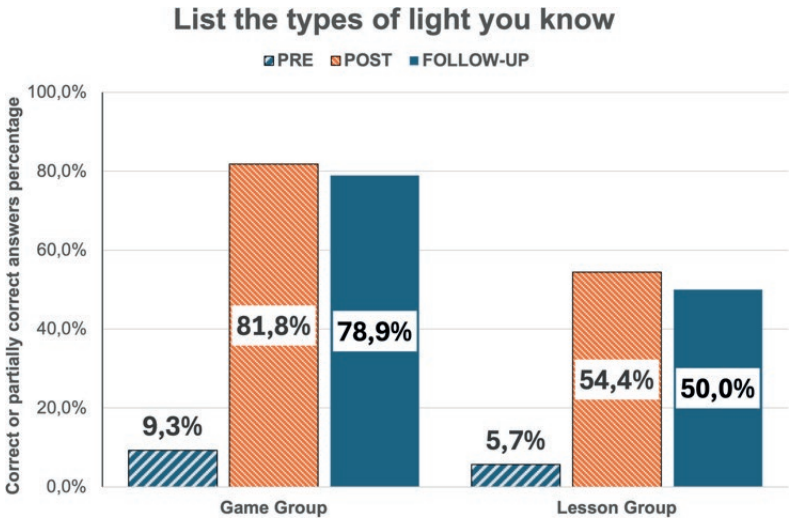

Figure 6. Correct or partially correct answers percentage to the question Q2.

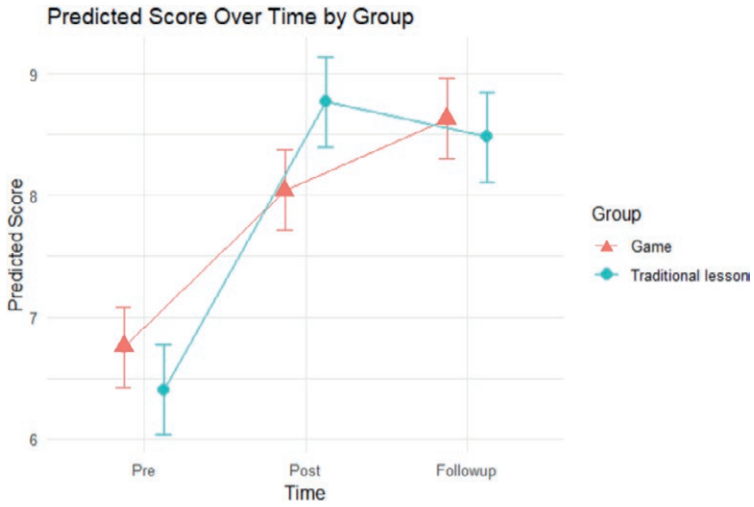

Figure 7. Predicted score over time of the question Q3: "Which of these are telescopes?".

The two groups show no significant difference in the estimated marginal mean of both phases since each mean values fall into the SE of the other one.

Figure 6 shows the results of question Q2. The Lesson Group performed a percentage of correct or partially correct answers of 5.7% in the pre-test, 54.4% in the post-test, and 50.0% in the follow-up test. On the other hand, the Game Group performed 9.3% on the pre-test, 81.8% on the post-test, and 78.9% in the follow-up.

For Q3 (Figure 7), the estimated marginal mean of scores in the pre-test is 6.75 with a SE of 0.17 for the Game Group and 6.40 with a SE of 0.19 for the Lesson Group, while in the post are 8.05 (SE 0.17) and 8.77 (SE 0.19), and in the follow-up 8.63 (SE 0.17) and 8.48 (SE 0.19), respectively.

We observe that both groups have the same prior knowledge about different kinds of telescopes, within the standard error. After the activity (post-test), the Lesson Group better recognizes telescopes

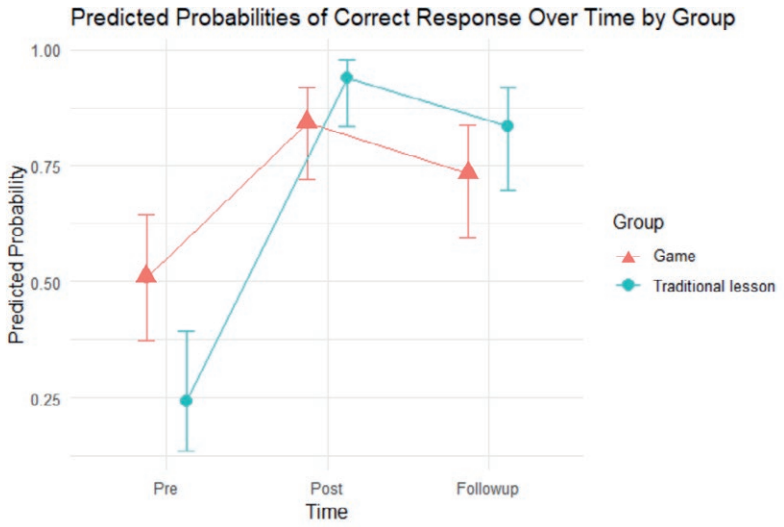

Figure 8. Predicted score over time of the question Q4: "What represents the three images shown here?".

than the game group. This result is likely because various types of telescopes are analyzed one by one and in more detail during the lesson. On the other hand, after four weeks (follow-up), the Game Group's response improves, becoming comparable to the performance of the Lesson Group.

The predicted probability of Q4, plotted in Figure 8, in the pre-test is 0.51 with SE of 0.07 for the Game Group and 0.24 with SE of 0.07 for the Lesson Group, while in the post are 0.84 (SE 0.05) and 0.94 (SE 0.03), and in the follow-up 0.73 (SE 0.06) and 0.84 (SE 0.06), respectively.

We observe that the Game Group had more previous knowledge about the images shown in question Q4 since they performed better than the Lesson Group in the pre-test. However, after the activities, the performances of the two groups are comparable within the standard error.

5. Discussion

The results shown in the previous section allowed us to better understand the potential of Cosmo Hunters to engage 13-year-old students in educational contexts and promote interest in the scientific aspects addressed in Table 1.

As expected, we observed that the GBL activity is more engaging than a classical frontal lecture in both average value and distribution (Fig 4). This is a typical result of innovative methods of education, particularly ones that involve games. The game is perceived as something new outside the classroom routine and, therefore, is more appreciated also because of the "novelty" effect.

Looking at the scientific aspects embedded within Cosmo Hunters, the results reported in section 4.2 proved that, overall, the GBL activity is able to promote interest with results comparable to a frontal lecture.

There are however some differences: regarding the nomenclature of frequencies of the electromagnetic spectrum (SA1), the Game Group reported more correct or partially correct answers than the Lesson Group. This result can be traced back to the intrinsic mechanics of Cosmo Hunters. The card mechanics require students to familiarise themselves with the nomenclature of the electromagnetic frequencies to play effectively. This helped to stick more firmly the nomenclature in the students' memory

and to associate more deeply with the concept of the electromagnetic spectrum (which was later introduced during the debriefing), compared to a frontal lesson.

Another peculiarity lay in the results of Q3, regarding the images of the telescope (SA2). The Lesson Group performed better than the Game Group right after the activity, while the predicted scores were similar (no statistical difference) in the follow-up.

This is probably because, in the lesson, we had more time to deepen the nomenclature and visuals of different telescopes used for astrophysics observation. In the GBL activity, instead, both in the game and during the debriefing, we focused more on the necessity of having different kinds of telescopes for observing different frequencies rather than focusing on the nomenclature and visuals of these telescopes due to time limitations.

Furthermore, the understanding of multifrequency observation (SA3) is comparable for both groups in the post-test and the follow-up. It's worth mentioning that the SA3 in the GBL activity was conveyed more through a strategy choice than a game mechanic. Players can choose whether to collect Observation cards of the same objects at different frequencies to score more points or apply another strategy. This means that, even if there were no explicit push to multifrequency observation in the game, the strategic necessity to score more points via these card combinations leads to a deeper understanding of the astrophysical concepts, comparable with a frontal lesson.

We can conclude that Cosmo Hunters is an effective tool to engage and promote interest in 13-year-old students in educational contexts regarding the electromagnetic spectrum and astrophysical observations. The game is a valid alternative to a frontal lecture, with a higher engagement perceived by participants, and low effort required to implement it.

In particular, we observed that the scientific aspects embedded in Cosmo Hunters had different interest levels in the students according to the different ways they are implemented:

- SA1 is implemented as a core mechanic of the game. This is the primal level of engagement and access to the game and for this reason, the nomenclature of the electromagnetic spectrum used in this mechanic had a greater impact and interest for the students;
- SA2 is implemented both as a game mechanics (different telescopes necessary to observe) and aesthetic (different images for the different telescopes) of the game. For this reason, while the mechanic part of SA2 is interesting for students, the aesthetic parts asked in Q3 may be less interesting;
- SA3 is implemented as a game strategy, therefore requiring a more profound knowledge of the game dynamics to be perceived. Nevertheless, the simplicity of the Cosmo Hunters allowed to obtain an interest in this topic comparable to a frontal lecture.

This hierarchy of results is consistent with the literature that suggests that learning outcomes can be reached more effectively through game mechanics rather than the content alone (Bayeck, 2020; Yoon & Khambari, 2022).

6. Conclusion

Cosmo Hunters is a card game developed by Giannandrea Inchingolo in collaboration with INAF – Osservatorio Astrofisico di Arcetri and GAME Science Research Center.

Its goal is to introduce – in the span of a 15-20 minutes gameplay – the topic of astrophysics observations of celestial objects at different frequencies of the electromagnetic spectrum with upper primary and low secondary school students.

In this study, we tested the potential of Cosmo Hunters to engage 13-year-old students in educational contexts and to promote interest in three scientific aspects addressed by the game, i.e., the existence of different frequencies of the electromagnetic spectrum using astrophysics observation as a scientific context (SA1), the necessity to use different kind of telescopes for astrophysics observations (SA2), and the possibility to observe the same astrophysical object at different frequencies to have more information (SA3). We tested the engagement and interest effect of Cosmo Hunters compared to a classical frontal lecture and verified its long-term endurance after four weeks.

We involved two groups of students: the Game Group and the Lesson Group. The Game Group (99 students) attended a GBL activity composed of gameplays and a debriefing session, while the Lesson Group (76 students) attended a frontal lesson with the same content as the game.

The data collection was made through three questionnaires administered before starting the activity (pre-test), at the end of it (post-test), and after four weeks (follow-up).

Results showed that the GBL activity was perceived as more engaging than the frontal lecture. Indeed, the Likert scale evaluation reported an average enjoyment of 6.0/7 for the Game Group and 5.3/7 for the Lesson Group.

The analysis of the interest in scientific topics, on the other hand, gave different results for the three scientific aspects addressed by the game.

SA1, being a fundamental game mechanic, raised more interest than a traditional lecture. SA2, which was introduced through the aesthetic of the game, i.e., the images on the Telescope cards, proved to be more interesting in a traditional lecture than in the game. SA3 is addressed through a game strategy rather than a game mechanic. Therefore, it is tied to understanding the game's dynamics rather than just its rules, i.e., requiring more effort to achieve it compared to SA1. Even considering this aspect, the topic has obtained the same results compared to a frontal lecture.

From this analysis, we encourage using Cosmo Hunters as a GBL activity to introduce the basic concepts of the electromagnetic spectrum and how astrophysics observations exploit it to study celestial objects.

Moreover, thanks to the short duration of the gameplay (15-20 minutes), the game can also be used after the GBL activity in the class as a filler during free time – without preparation or intervention by the teacher – to reinforce the learning in a fun and enjoyable environment.

The game is fully described at play.inaf.it/en/cosmo-hunters-en/, and a Print&Play version of the game is also available to reproduce the activity in the classroom. We also developed a guide for facilitating the game-based learning activity that is available on the same webpage.

For future usage of Cosmo Hunters in GBL activities, we recommend doing a one-hour activity composed of a single gameplay followed by a debriefing of at least 30 minutes. For the debriefing, we reported the questions used in the Appendix as guidelines, and we suggest assessing in more detail the topics of multifrequency observation, improving the educational response of the students compared to the one obtained in this study.

7. Funding

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8. Acknowledgments

We thank the ICS 'Compagni-Carducci' schools in Florence and ICS 3 in Quartu Sant'Elena (Cagliari, Sardinia) for the collaboration.

We want to acknowledge Marcello Passarelli for his contribution to the result analysis.

9. Appendix

9.1. Pre-test

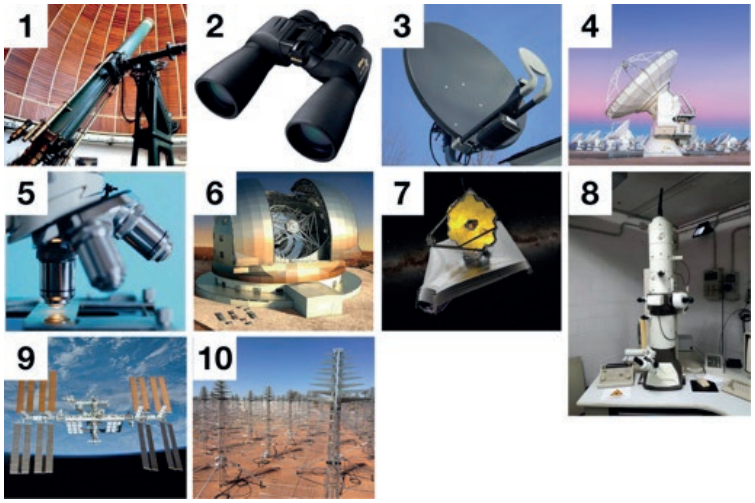
1) Which of these objects emit light?

2) Specify what type of light the selected objects emit.

3) What represents the three images shown here?

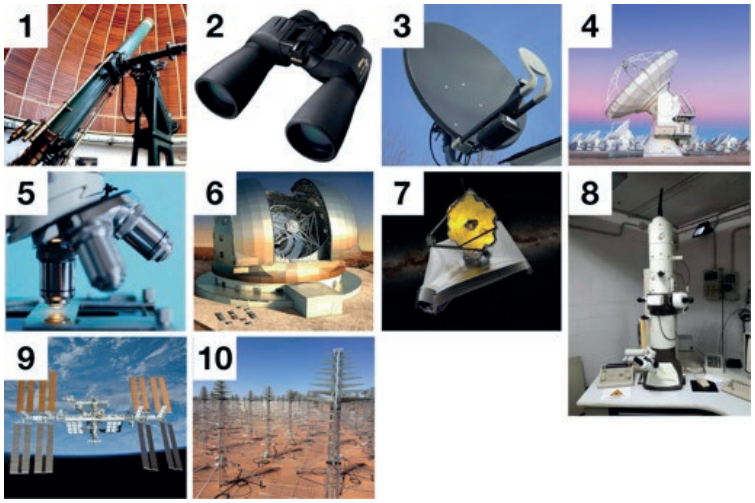
o All the same nebula, but observed at different frequencies
o A galaxy, a nebula, and a black hole
o All galaxies, but of different types
o All the same nebula but observed at three different stages of its evolution.

4) Which of these are telescopes?



9.2. Post-test

1) On a scale from 1 (not at all) to 7 (very much), how much did you enjoy today's activity?
2) Which of these are telescopes?



3) What represents the three images shown here?

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o All the same nebula, but observed at different frequencies
o A galaxy, a nebula, and a black hole
o All galaxies, but of different types
o All the same nebula but observed at three different stages of its evolution.

4) What types of light do you know?

9.3. Follow-up test

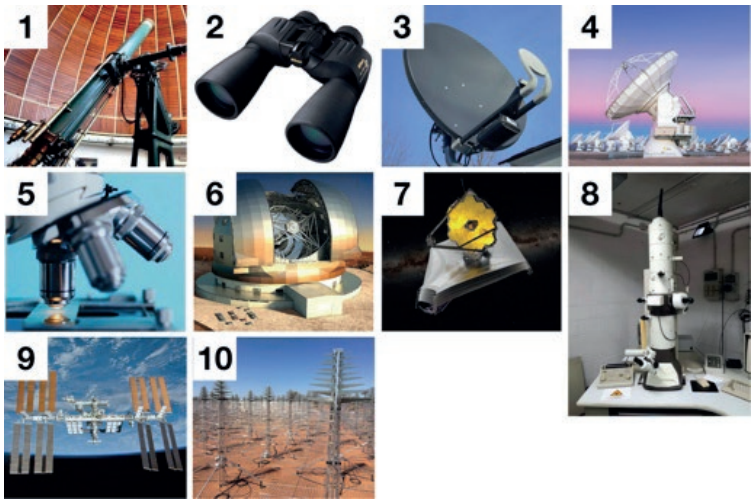
1) List the types of light you know.
2) Which of these objects emit light?

3) Arrange the following light frequencies from least energetic (lowest frequency) to most energetic (highest frequency). VISIBLE – X-RAYS – INFRARED – ULTRAVIOLET – RADIO – GAMMA RAYS – MICROWAVES

4) What represents the three images shown here?

o All the same nebula, but observed at different frequencies
o A galaxy, a nebula, and a black hole
o All galaxies, but of different types
o All the same nebula but observed at three different stages of its evolution.

5) Which of these are telescopes?



9.4. Frontal lecture

The frontal lecture comprehended the following arguments:

- what is astrophysics, and what does it mean to observe something (difference between light emitted and reflected)
- what is light (hints of dual nature)
- fundamental aspects of electromagnetic waves (wavelength, frequency, energy and their correlation)
- the electromagnetic spectrum (different kinds of light)
- different lights for different information (when studying a celestial object, it is important to look at every radiation emitted to obtain more details about its functioning)
- a detailed description of every frequency band (which kind of telescopes are needed to observe it, an example of a celestial object that emits it and how we use it in our daily lives)

9.5. Debriefing

During the debriefing, facilitators promote discussion among participants trough the use of the following questions. We highlight also that during the debriefing we used the questions of the post-test to simultaneously collect our data and use them to promote discussion along with the students:

- Did you have fun? What did you like the most, and what did you like the least?
- What were the winning strategies? What were the losing ones? Who won, and why did they win?
- Quick presentation of the main frequencies of the electromagnetic spectrum and their use in our daily lives
- [Display 10 image objects] Which of these objects emit light? Why?
- [Display 6 types of electromagnetic frequencies] Arrange the following types of light in order of increasing energy
- [Display the three Observation cards representing the same celestial object seen through different frequencies] Why do these cards give more points when they are collected together?
- Why do you need a corresponding Telescope card to score points with the Observation cards? For the Visible cards, it wasn't necessary. Why?

- Brief explanation of the different type of telescopes.
- [Display 10 image instruments] Which of these instruments are telescopes?

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"Social Media Puppeteers", "Social Media Fake News" and "Data Defenders": Games and video games to promote youngsters' information and media literacy

"Social Media Puppeteers", "Social Media Fake News" and "Data Defenders": giochi e videogiochi per promuovere la media e information literacy nei più giovani

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ABSTRACT Video games have acquired heightened relevance following the experiences endured during the pandemic, notably concerning personal well-being and social connections. This contribution presents the tangible outcomes of the project YO-MEDIA – Youngsters' Media Literacy in Times of Crisis, specifically the board games "Social Media Puppeteers" and "Social Media Fake News", and the video game "Data Defenders", which are the result of the design and production efforts of the project team. The article focuses on the mechanics, graphic choices, characters, and atmospheres of games. The ultimate goal of the products is to support the development of skills in young people through play, engagement, and direct participation, while introducing key techniques underlying pre-bunking and the strategies for debunking fake news, through the characters' actions. During the games, the participants are called upon to produce information, deconstruct it, and verify sources.

KEYWORDS Game-Based Learning; Media and Information Literacy; Fake News; Disinformation; Serious Game.

SOMMARIO I videogiochi hanno acquisito un nuovo respiro a seguito delle esperienze vissute durante la pandemia, in particolare per quanto riguarda il benessere personale e la connessione sociale. Il contributo presenta i risultati tangibili del progetto YO-MEDIA – Youngsters' Media Literacy in Times of Crisis, in particolare i giochi da tavolo "Social Media Puppeteers" e "Social Media Fake News" e il videogioco "Data Defenders", frutto degli sforzi di progettazione e produzione del team di progetto, con particolare riferimento alle meccaniche, alle scelte grafiche, ai personaggi e alle atmosfere delle proposte ludiche costruite. L'obiettivo ultimo dei prodotti è di sostenere le competenze dei ragazzi attraverso il gioco, il coinvolgimento, la

partecipazione diretta, incontrando le principali tecniche alla base del pre-bunking e le logiche di smascheramento delle fake news, attraverso la scelta delle azioni dei personaggi. Nel corso dei giochi, i ragazzi sono infatti chiamati a produrre informazioni, scomporle e verificare le fonti.

PAROLE CHIAVE Game-Based Learning; Media and Information Literacy; Fake News; Disinformazione; Serious Game.

1. Introduction

The contemporary youth cohort is confronted with many transformative dynamics and adversities, which have garnered significant attention in the media landscape. Cultivating dynamic literacies (Potter & McDougall, 2017) emerges as imperative for navigating through the deluge of information and discerning falsehoods, particularly when news is accessed through unfiltered social media channels (Lauricella et al., 2020; Krumsvik, 2023; Santos et al., 2023). In particular, Meta's recent decision (January, 2025) to review and remove third-party independent fact-checking organizations seems to support this need.

Since the early 20th century, historical tradition – exemplified by Marc Bloch's (1921) studies on fake news during World War I – and the tradition of communication sociology, including Walter Lippman's (1922) journalistic sociology approach, Harold Lasswell's (1927) political analysis of media content, and Sergej Tchackotine's (1939) psychological analysis of Nazi propaganda techniques, have emphasized that the democratic function of the media (Mannheim, 1940) is undermined during wars and other crises. These periods are marked by an increased use of manipulative strategies to shape human behavior and social relations (Gili, 2001). In reality, the media cannot escape the suspicion of manipulation, historically situated in specific contexts, throughout the century, and it is partly to respond to this suspicion that Media Education emerged in the second half of the 20th century, based on education in critical thinking (Carenzio, 2024; Rivoltella, 2017).

However, with the new informational ecosystem defined as the "infosphere" by Floridi (2014), this disciplinary field needs to complement education in media consumption with education in media production and responsibility – that is, evaluating the consequences of one's actions in the social web – a concept that becomes central in the prevention and contrast of behaviors associated with cyber stupidity (Pasta, 2018). The individual who must resist media and manipulative attempts is no longer just a spectator but has become a "prosumer" (Pasta, 2021). The result is a profound sense of inadequacy regarding literacy, a perspective that has been present and highlighted for at least a decade (Banzato & Midoro, 2013), considering literacy as a "complex phenomenon" (Banzato, 2011 and 2013) in a plural and multi-multi-dimensional framework (The New London Group, 1996).

This shift also affects Information Literacy (Ferrari & Pasta, 2023), as one of the novelties introduced by the web is the proliferation of data and information in digital form, requiring new types of literacies. Competency is no longer so much about finding and accessing sources but about evaluating them, facing information overload, fragmentation, decontextualization, mutability and transience (sources can be continuously updated), unpredictability, and qualitative inconsistency. The web confronts us with the impossibility of total knowledge, shifting the aim of education to creating a coherent framework for "meaning making", a process that is particularly delicate, and necessary at the same time. This is especially important in the current geopolitical climate as, for example, the war in Ukraine provides strong motives to spread misinformation and propaganda.

In this scenario, Media and Information Literacy is even more relevant and should be fostered with different perspectives and approaches, such as ludic tools, games and video games. Video games, in particular have acquired a increased recognition following the experiences endured during the pandemic, notably concerning personal well-being and social connection (Cauberghe et al., 2021; Johannes et al. 2021; Kriz, 2020). As we will see in the next section, games and video games support a critical and participatory engagement among youth, facilitated by narrative immersion, identification mechanisms with characters or stories, interactive elements coupled with the allowance for failure, and the necessity to formulate strategies applicable beyond the gaming realm (Bunt & Grosser, 2020; Moro et al., 2022).

The contribution presents the tangible outcomes of YO-MEDIA, Youngsters' Media Literacy in Times of Crisis (Carenzio et al., 2023 and 2024), specifically the board games and the video game designed within the project funded by the European Media and Information Fund (EMIF), which involved partners from Italy, Portugal and Spain to design and implement games focusing on misinformation/disinformation, and information literacy in times of crisis.

The structure of the contribution presents four main sections: the first is dedicated to the framework, discussing the role of games in engaging young people. The second section presents three ludic products to support Media and Information Literacy with different structures and game experiences. Social Media Puppeteers is a micro TTRPG (tabletop role-playing game) adapted and customized to create an educational experience focused on media literacy, critical thinking, and social media dynamics. Social Media Fake News is a card game designed to help players recognize the features that can make a news story misleading or false. The goal is to be the first to run out of cards by constructing a fake news story. Data Defenders is a tower defense digital game that blends narrative and engaging mechanics to highlight media literacy during crises, where players become defenders of global data servers amid an alien invasion and a devastating pandemic. The third section presents the methodological framework with the study protocol of the games, while the fourth is dedicated to the main results. The contribution is concluded with final reflections.

2. Games to engage young people

A challenge in contemporary education is implementing innovative teaching methodologies that can effectively keep pace with rapid societal changes (Martinez et al., 2022), including swift advancements in digital technology and recent global crises, such as health and geopolitics. This challenge is particularly pertinent given the characteristics of today's young people, who demand engaging educational approaches. The interactive nature of games, and in particular the immersive nature of video games (García-Gilet al., 2023), have proven particularly captivating for youth, presenting an opportunity to make learning and personal development more appealing and effective. The incorporation of gamification strategies, such as point systems, achievement badges, competitive rankings, and progressively challenging difficulty levels, has been demonstrated to encourage students to engage more deeply and meaningfully with learning materials (Harrison, 2022; Martins et al., 2024).

Studies have shown that well-designed educational games can significantly enhance interdisciplinary learning and boost cognitive skills, improving academic performance across various subjects, including mathematics, history, and English (Martinez et al., 2022; Tuan et al., 2024). For instance, several studies highlight the use of Minecraft: Education Edition to engage young people in co-constructing knowledge and peer teaching (Holik et al., 2024; Hughes et al., 2024; Sulaiman et al., 2024).

Additionally, game-based learning enhances young people's critical thinking, media and digital literacy, enabling them to evaluate multimedia information critically (Fadhli et al., 2023; Mao et al., 2022). Games can incorporate specific media literacy content, such as identifying false information, addressing digital security and privacy issues, and developing media skills (Contreras-Espinosa & Eguia-Gomez, 2023). This approach provides players with new experiences that prepare them for real-life problem-solving, especially during crises (Moro et al., 2022). While the potential benefits of game-based learning are numerous, it is essential to recognize that many educators may face challenges implementing these approaches in their classrooms (Diehl et al., 2024). These challenges can arise from a variety of factors, in particular when digital devices are needed:

Limited access to digital devices or outdated equipment can hinder the implementation of game-based learning (Shen et al., 2023).

The financial burden of purchasing educational games and technology can be prohibitive for many institutions, limiting their ability to implement game-based learning (Kraff et al., 2023).

The potential need for more necessary skills or the unwillingness of some educators to adapt to new teaching methodologies. This resistance to change can stem from various factors, including insufficient training, lack of confidence in using digital tools, or skepticism about the effectiveness of game-based learning approaches (Diehl et al., 2024; Misra et al., 2022).

Providing educators with comprehensive support that addresses pedagogical and practical challenges is essential to implementing effective game-based learning strategies in the classroom (Martinez et al., 2022). This support should encompass a range of resources, including access to appropriate technological equipment, well-designed lesson plans, and ongoing technical and pedagogical support. Additionally, it is crucial to offer continuous professional development opportunities to educators, and to refine their skills in implementing these innovative teaching methods (Baek & Ward, 2023).

Furthermore, even if not applicable in this project and specific case, game-based learning methodologies allow involving educators and students in co-creation of games, significantly enhancing the effectiveness of these initiatives (Fernandes et al., 2020; Weitze, 2018). This collaborative approach not only allows for the development of computational thinking skills and creativity among teachers and youth but also helps to maximize the educational potential of games by ensuring that they are tailored to the specific needs and interests of the student population (Sousa et al., 2023). By fostering a sense of ownership and engagement among all stakeholders, this participatory approach can help to overcome resistance to new teaching methods and create a more dynamic and effective learning environment.

In the following sections we will focus on the three products designed within the project.

3. Description of the games

3.1. Social media puppeteers and social media fake news

Two different board games have been designed.

The first is Social Media Puppeteers, a micro tabletop role-playing game incorporating elements of character creation and dice rolling found in traditional RPGs. Players assume the roles of politicians, journalists, scientists, or influencers, competing on a fictional social media platform to gain influence and promote media literacy. During the game, players earn points when they achieve goals related to their character's role and special abilities. Players take turns posting messages or content, trying to gain influence. To post content, players roll a D6 and add their character's specific bonus, according to their role. The player with the highest roll gains influence points and can spend them on special abilities or save them for later. Other play-

ers can comment or respond to the post and form alliances or rivalries by collaborating or challenging each other's posts. The game ends after 4 rounds or when a player reaches a predetermined influence goal. At the end of the game, the player with the most influence points wins. There is no losing condition.

Players can take on the roles of politicians, journalists (Figure 1), scientists, and influencers competing to capture the masses' attention and influence collective perceptions on the social media platform "Y".

Designed for 3 to 6 players, it can be adapted to accommodate larger groups if needed, in particular at school. The estimated time range is 60 minutes (including character selection, gameplay, and discussions), the time to play can vary depending on the group's familiarity with the game and the depth of the discussion phase during gameplay and postgame. However, it can be shorter (or longer) depending on the gameplay pace and the extent of classroom discussions and reflections, as it can also be played without classroom post-game discussions.

As the facilitator, teachers or educators play a crucial role in ensuring a smooth and educational gaming experience, establishing a respectful and inclusive environment from the start where respectful communication is key. Guidelines for implementation at school and extra-school contexts are included. For example, a school class can be involved in a sort of pre-game phase, introducing the concept of media literacy and discussing it in today's digital landscape. During gameplay, facilitators are suggested to periodically pause the game to support discussions, asking students how their character's actions on the 'Social Media Platform Y' align with their objectives and values. Recent examples of social media influence, misinformation, or viral content are also encouraged to draw connections between these real-world examples and their in-game experiences. After the game, teachers and educators can lead a reflective discussion, passing from the board game to real social media campaigns.

The second game (Social Media Fake News) is a card game designed for 2 to 6 players, although it is recommended to have more than two. The components required to play include a board (Figure 2), News Construction Cards, Action Cards, and Counterattack Cards, with Topic Cards being optional.

The game typically lasts about 30 minutes, but the duration can vary depending on how familiar the group is with the game and whether it's used in a classroom setting, where discussions may extend the time. However, it can also be played without classroom discussions. The player who has the most cards remaining at the end of the game loses.

To start, all the cards are shuffled together, and each player is dealt six cards. The remaining cards form a 'News Construction' pile, placed face down. The game begins with the first player drawing a News Construction Card to determine the news topic. The order of the columns in the game, dictating the sequence in which players must play their cards during the first round, starts with "Sensationalistic Headlines". For example, in this step players use eye-catching and exaggerated headlines to immediately capture the reader's attention, even at the expense of accuracy or neutrality. This is followed by the "Exaggeration of Facts" where players amplify or distort information to make it more sensational or dramatic than it truly is. Once the black line on the board is reached in the first round, a news headline is considered created, and players begin a second round.

The columns for creating news are based on the code of the Federación de Asociaciones de Periodistas de España, FAPE[1] (Spanish Journalists' Associations Federation), and the World Ethical Charter for Journalists (June 2019) from the International Federation of Journalists[2].

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[1] Federación de Asociaciones de Periodistas de España, FAPE: https://fape.es/home/codigo-deontologico/

[2] International Federation of Journalists. https://www.ifj.org/es/quien/reglas-y-politica/carta-mundial-de-etica-para-periodistas

social media puppeteers

JOURNALIST CHARACTER SHEET

Character description:

Name:

Background:

Appearance:

Attributes:

Impact	Reputation	Luck	Influence

Backstory:

Note: Create a brief backstory for your character, outlining their motivations and values.

Influence points:

Current influence:

Note: Use this section to record your character's posts on "Social Media Platform Y". Describe the content, strategies, and objectives for each post. You may use additional sheets if needed.

Character's posts

Content: 1	Content: 2	Content: 3
Objective:	Objective:	Objective:
Strategy:	Strategy:	Strategy:

Allies

Rivals

Figure 1. Example of a character sheet.

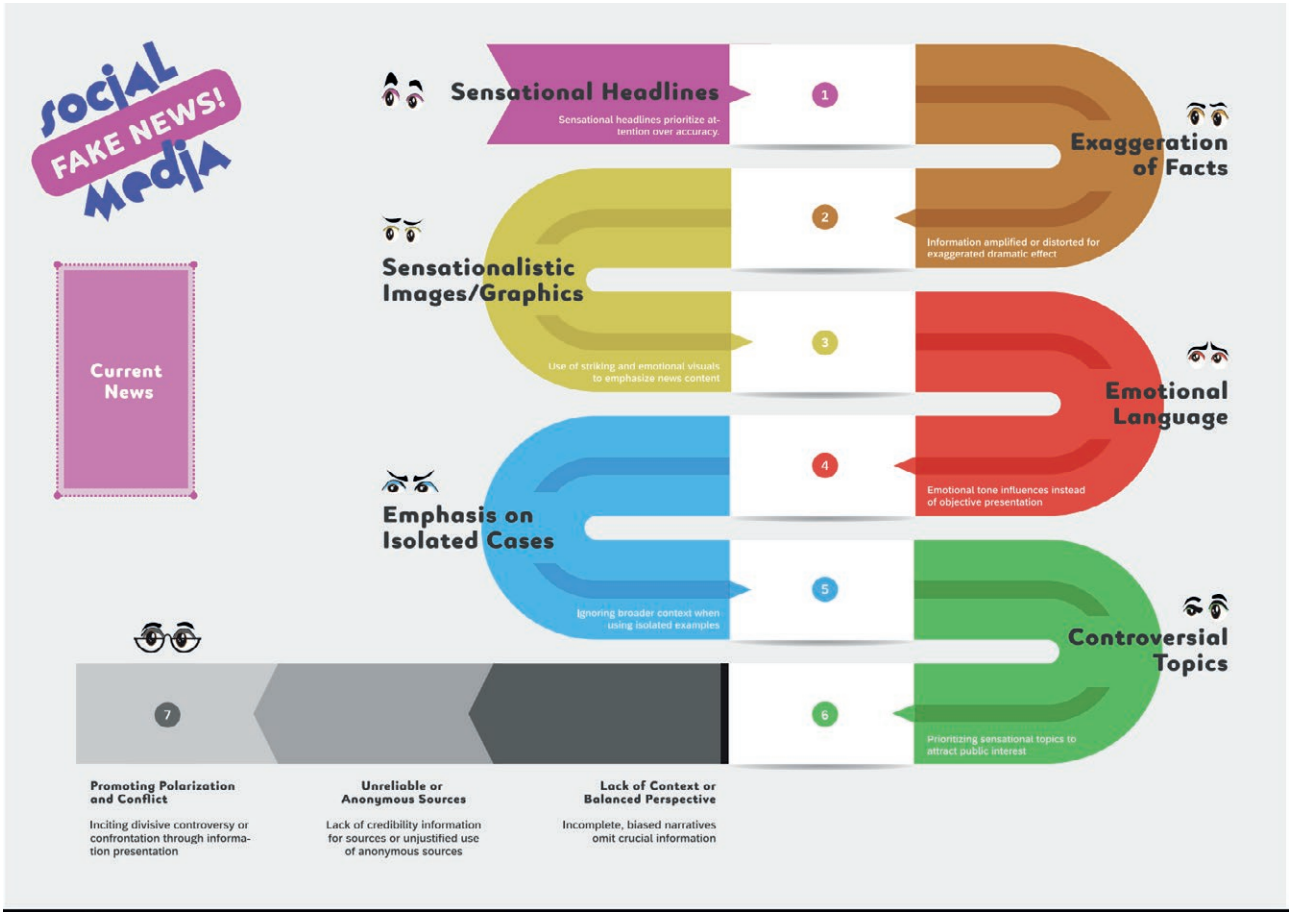

Figure 2. Board.

3.2. Data Defenders

In this digital game, Planet Earth is under attack by robots spreading false information through servers accessed by the Earth's population, causing widespread panic. The game unfolds across three islands, each featuring a unique playable character (see Figure 3): the Journalist Island – Chronicle Cove hosts Carlos Castillo, a journalist for Citizen's Current tasked with gathering information and reporting live from the scene; the Influencer Island – Iconic Bay with Ivy Ingram, an influencer recently hospitalized with the Alienfect-120 virus; the Politician Island – Ruler's Realm introduces President Robert Rogers, the most influential character in the game, aiming to uncover the aliens' motives and end the war (Figure 3).

The game is crafted with players aged 13 and above in mind, appealing to teenagers and young adults who enjoy mobile gaming experiences.

The game adheres to the core mechanics of a classic tower defense game. Robots move across a designated path, aiming for servers at the end. Players must eliminate multiple waves of alien robots, preventing them from breaching the servers and spreading false information on the Internet. Players strategically position various towers along the path to achieve this, utilizing their energy reserves to target and destroy the invaders.

Figure 3. Journalist, Politician, Soldier, Doctor and Influencer.

Beyond the tower defense mechanics, two innovative core mechanics define the gameplay experience: the Data Analyzer (Figure 4) allows players to dissect and assess various media content, including news articles and social media posts; the Crisis Impact Index, a dynamic meter reflecting the prevalence of misinformation in the game world and how effectively players manage the crisis.

The game is designed to enhance media literacy skills and promote critical thinking. By challenging players to analyze and evaluate information critically, the game aims to cultivate the ability to discern fact from fiction and make informed decisions. It empowers players to combat misinformation within the created universe, fostering a sense of agency in navigating digital media environments responsibly.

The game can be integrated into disinformation literacy sessions as an interactive learning tool. Participants engage with the game's mechanics and storyline, applying critical thinking skills to combat misinformation in a controlled environment. This interactive scenario provides a compelling basis for discussion and analysis, allowing participants to explore the motivations behind misinformation and strategize solutions to mitigate its effects. After gameplay, participants are encouraged to engage in reflective discussions to debrief on their experiences, share insights, and reinforce key media literacy concepts and critical thinking.

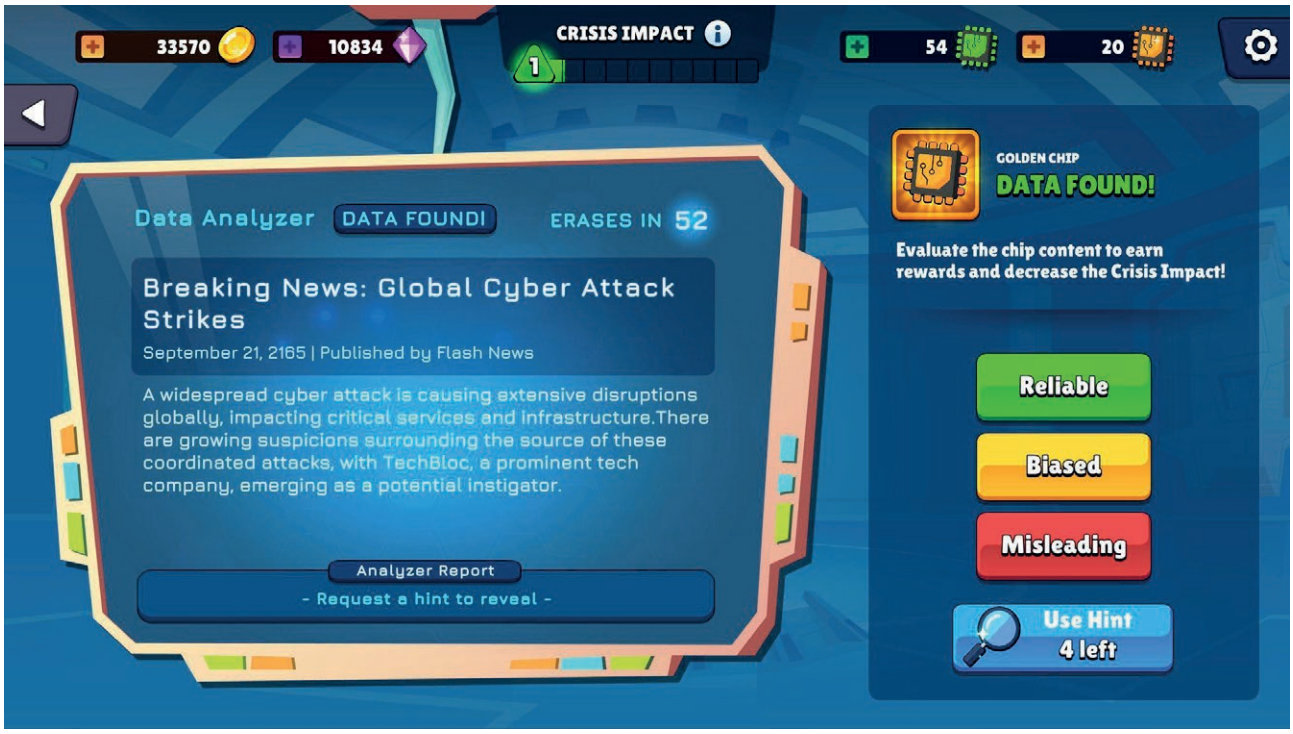

Figure 4. Data Analyzer.

4. Method

In this section, we will present the testing phase of the games, before the final concept and graphical design.

4.1. Testing the board games

Social Media Puppeteers and Social Media Fake News have been tested on different occasions, at the La Salle Training Center, at ENTI-UB Training Center, and at the Universidad de Guadalajara (this last venue only referred to Social Media Puppeteers). Students' profiles combined diverse educational backgrounds, with prior knowledge of technology and social media. Meanwhile, at the ENTI-UB Training Center, students were attending training related to technology and digital fields, demonstrating a clear familiarity with social media.

Regarding the first game, the micro tabletop role-playing game involved 30 students aged 16-19 years (12 F and 18 M). Students were divided into small groups of 5-6 students each. Social Media Fake News was tested with 16 students aged 16-19 years (9 F and 7 M), 19 students aged 18-20 years (9 F and 10 M), and 12 students aged 17-19 years (7 F and 5 M). These students were grouped into small teams of 3-4 members per team.

An exploratory and descriptive methodology was used, in which participants played Social Media Fake News and Social Media Puppeteers games during a controlled two-hour session, with four rounds played per group. The sessions were designed to observe how the participants interacted with the games, their level of understanding, and their reactions to the various scenarios presented. In terms of procedure, the steps included three levels:

1) A preparatory phase: Before the game, participants were informed about the objective of the games, their functionality, and the basic rules.
2) A core phase dedicated to gameplay: Each group played for approximately 20 minutes during the session. Parallel, non-intrusive observations were carried out to collect information about players' interactions with the interface, their approach to challenges, and group discussions.
3) Post-session discussion: Students participated in an open discussion to share their experiences and comments about the games.

Data were collected mainly via direct observation. During sessions, facilitators took detailed notes on players' interactions with the game, including response times, specific behaviors during the session, and the level of involvement. Informal interviews conducted at the end of the sessions explored participants' opinions about the games.

4.2. Testing the digital game

The digital game passed several testing phases, both on a technical and a gameplay level, regarding the structure and the mechanics. In this section we will present the study protocol developed to accompany the gameplay sessions with Data Defenders in schools.

The protocol includes pre-and post-tools and gameplay observation sessions to inform revisions and study students' feedback, according to three steps:

1) The first involves administering a questionnaire[3] to all students involved (15-18 years old) where the digital game has been introduced and tested. The questionnaire helped identify the students for the gameplay session (N=6), considering students' profiles, gaming experience (experienced gamers, casual gamers, or non-gamers), critical thinking ability, problem solving, and Information Literacy, and gender.

2) The second step comprises a gameplay session and the use of a grid (derived from game designers' observation practices) to observe students while playing, observing both students' interaction and their reaction to game mechanics with a qualitative approach.

3) The third step includes a post-gameplay session on two levels. The first individual data collection via a user experience form, coded with students' ID numbers. These forms provide insights into personal gaming experiences and perceptions. The second involves a plenary session with a group discussion aimed at exploring shared experiences and drawing collective insights.

Currently, the protocol has been applied in two occasions: in a secondary school in a district of Milan (Italy) during daily school activities, involving 6 school classes (3 fourth-year classes and 3 fifth-year classes of a Scientific High School – Sciences and Applied Sciences track), and within the National program "Cientificamente Provável" (Scientifically Probable) with 6 students and 3 teachers from a secondary school in the Aveiro region (Portugal). This initiative intends to create partnerships between schools, research units, and higher education libraries, enriching students' educational experience through direct experience with researchers and higher education institutions.

[3] https://shorturl.at/me7qT

5. Results and discussion

5.1. The board games

The results helped inform adjustments to improve gameplay balance and design of the board games.

In Social Media Puppeteers, observing group dynamics allowed game developers to adjust the recommended playtime and to define specific guidelines included in the support cards, such as instructions for "creating a digital adventure".

Modifications were made to the game elements to balance the mechanics and reinforce the educational goals, such as understanding how the media seek to maximize the impact of news. For instance, certain strategic points were assigned a value of 2 over others, encouraging players to prioritize these actions within the game.

In Social MediaFake News, prior to the testing sessions, we had a total of 167 cards, excluding the Crisis Cards. This made progress in the game challenging, so the set was simplified to a total of 108 cards, consisting of 72 construction cards and 36 action cards. This decision ensured a more equitable distribution, improving the overall game dynamics.

It was also observed that games with only two players slowed down the pace and limited the debate dynamics. In contrast, with a minimum of four players, richer discussions emerged about the creation of news within the game and the events represented. Students' insights include:

"The game feels like it takes forever to finish when it's just the two of us".
"When there are four of us, the conversations become much more interesting".
"It's more fun because we all contribute different ideas, and there's more debate about the cards".

This finding prompted the inclusion of new alternative dynamics in the game rules. For example, "Building Statements" challenges players to create coherent and creative statements using the available cards, while "Matching Colors" focuses on quickly pairing cards by color without requiring complex statements.

In both games, tests were also crucial in adjusting the graphic elements to align with the participants' communication needs and reduce cognitive overload (Kalyuga & Plass, 2009), beyond specific impairments. In Social Media Fake News, users reported difficulties in distinguishing the cards, leading to improvements in color contrast, requesting a reorganization of visual elements, and the addition of a distinctive design with eye illustrations in order to limit visual fatigue. This change aimed to facilitate card identification, particularly for colorblind players (Heron et al., 2018).

These modifications resulted in greater visibility and a significantly improved user experience, preventing the board games' feeling of "fiddliness" (Passarelli et al., 2024).

5.2. The digital game

The study on the video game is now ongoing. We will discuss the preliminary results from the Italian school. Even with a very limited sample size (N=6 students), the study protocol helped reach two goals. The first goal is connected to the testing of the protocol itself, evaluated according to the following criteria: completeness of the requests, logical order of presentation, coherence and clarity in the formulation of the questions, suitability of the response methods, effectiveness of the questions. Overall, the protocol showed to be robust and relevant, although the session led to one change in the section dedicated to the questions on Information Literacy.

The second goal is related to the game Data Defenders and its potential to support knowledge and skills, helping students reflect and promote critical explorations within the world of data and information today.

A few issues related to the game (not to the contents) were identified during the focus group.

The first issue is connected to Gee's work and the principle of exploration (Gee, 2013), emphasizing the role of active engagement and discovery as learning key components:

> *"In the second level I tried to focus more, and I looked at the archive of questions to try to better understand how to respond. For the second question, I was much more satisfied, I finally understood the logic".*
> *"At first I was a bit random in my choices, but then I realized that every resource mattered, and I adjusted my strategy to improve my score".*

The second issue refers to the role of immediate feedback, that is, the real-time responses or reactions provided to single actions, essential for guiding the player, reinforcing learning, and maintaining engagement:

> *"I also repeated the third level, and it didn't go very well. I had to adapt the strategy, but the lack of clear feedback made everything a bit frustrating. With notifications after each mission was completed, it would have been much more motivating".*
> *"I think notifications for progress and missions would make the game more motivating. Having continuous feedback would help better understand what to do".*

The third issue hits the core of the project: letting students' play, enjoy the game and learn new skills to be shared in everyday life:

> *"It made me more aware that every piece of information requires evaluation. Now, I think I'm more attentive even outside the game".*
> *"I've noticed that these literacy skills can be useful in many contexts".*

The analysis of the observation grid, even if preliminary and based on a single group, helped to assess several elements on a scale from 1 (low) to 4 (high) with qualitative observation notes: menu navigation, active engagement, emotional engagement, verbal communication, reaction to the game obstacles, attention to details, adaptability.

The interface was clear and easy (4 is the main score attributed to 4 students, 3 to the rest of the group), the engagement was deep (4 to all the students), with a single student showing distraction (score 2). The emotional level of students' engagements has been observed concerning facial expressions (smiles, surprised glances), and postural elements. However, in two cases, students expressed frustration while playing as they were not able to pass the level and win (score 2 and 1 referred to visual and sound elements). Verbal communication was relevant for four students, with comments and ideas expressed verbally and shared when playing, while playing was mainly a silent activity for 2 students. Mistakes and obstacles usually made players change their strategy, no one checked for support or help in the game tutorial. As for the attention to the details, except for one player who did not notice supporting elements in the game, everyone used the hidden information and the details disseminated in the scenario, even when not so immediate. In terms of adaptability, players made an effort to react, change behaviors (4 is the main score), and they used their time to improve the final score, despite the school setting and the time limit (4 is the main score for 5 students).

6. Conclusion

Board games and digital games developed in this project result from a collaborative effort between game developers – focused on technical choices and narrative development – and a pedagogical viewpoint, informed by the working group and the feedback gathered from stakeholders during the initial phase of the project.

These game proposals share at least four key elements: attention to the educational context, connection with literature and strategies for preventing misinformation, emphasis on group dynamics, and language that resonates with young people.

Regarding the first key element, the games (both analogue and digital) are specifically designed for educational settings. However, they also incorporate a crucial insight shared during discussions with teachers, educators, and journalists (Carenzio, 2024a). In particular, educators emphasized that when addressing social messages, game mechanics and learning objectives should be seamlessly integrated, making it difficult to separate the social content from the gameplay. Otherwise, there is a risk of creating a "foreign body effect," where the social message feels disconnected from the game. In other words, the playfulness of the game must be effective in engaging players.

On the second level, literature analysis and study of existing games have highlighted relevant aspects, such as adopting "prebunking" strategies. In prebunking, the audience is engaged preemptively to recognize the nature of information by understanding the techniques determining whether it is true or false, thereby building a kind of "preventive resistance" to misinformation. In contrast, debunking involves identifying and refuting false information after it has already spread, following the logic of what is termed "meticulous exposure". As social psychologist Sander van der Linden suggests, prebunking could help achieve a form of herd immunity against misinformation, limiting its impact (van der Linden, 2023).

In addition, literature on video games highlights how they allow players to simulate real-world problems and explore solutions, reducing the risks and negative consequences of incorrect choices. This enhances players' sense of agency in protected environments. Simulating and practicing within games support skill development, where "making mistakes" becomes a valuable part of learning. Based on Erickson's concept of a psychosocial moratorium in adolescence, Gee argues that video games create safe spaces for experimentation, reducing the pressures of real-life consequences (Gee, 2003). In a video game, exploration is not just about moving through levels, but about making decisions, testing ideas, and solving problems in an ever-changing and dynamic context. This mirrors the process of learning, where understanding grows through active exploration, critical thinking, and application. Through this lens, video games become powerful tools for learning, fostering autonomy, motivation, and personal growth. Players take on different roles, make difficult decisions, tackle problems, and test various strategies – all without the negative outcomes they might face in real life.

The third key element centers on group dynamics. The ability for players to form teams, collaborate, and develop shared strategies is particularly significant. An example can be found in the game Social Media Fake News, where players collaboratively create fake news. In education, fostering collaboration is crucial as it emphasizes knowledge as a social construct, emerging from dialogue rather than being owned by a single individual. This aligns with teachers' feedback, where peer tutoring strategies have proven effective. In particular, proficient students can support peers struggling with certain concepts, including technology-related topics.

Lastly, the fourth element involves connecting with young people through game design. The characters, such as influencers, are relatable to the world of social media and everyday life. Similarly, the

news to be analyzed in Data Defenders and the prompt cards used to create fake news in Social Media Fake News resonate with younger audiences. The settings, game mechanics, atmospheres, and graphic elements are designed to feel authentic and credible. Also, the elements we collected indicate the need to support young people, providing more guidance, and helping players to understand cause-and-effect relationships in the game world. Game designers have already worked on feedback to improve this part of the game, in particular in data Defenders, providing answers to make players understand mistakes or support better choices in the game.

Educators, teachers, and trainers can choose these games to implement diverse pedagogical strategies and explore various themes, using both analog and digital approaches depending on the context, complexity, and available time. Game sessions can range from 20 minutes to more extended activities of up to 60 minutes, fitting into both school schedules and extracurricular settings. It is also possible to revisit game sessions by selecting specific news items, products, or outcomes to facilitate further discussion and deeper exploration of relevant topics, aligned with the principles of digital education. In this way, games act as a bridge, mediator, and catalyst for new activities. For instance, incorporating current events, social media trends, or recent news into gameplay can engage participants and provide a relevant, real-world context. Students provided valuable feedback and expressed strong support for the game's role in developing media literacy skills. Their suggestions for future levels contributed significantly to the development plans (for example, including a new island on Artificial Intelligence in Data Defenders). The experience also offered students hands-on exposure to digital education tools and research methodologies.

In conclusion, the games are designed to immerse players in complex scenarios that challenge them to engage in strategic planning, evaluate consequences, and navigate moral dilemmas. Ultimately, this interactive and immersive approach can foster intergenerational dialogue and engagement across diverse audiences, emphasizing the importance of building a dynamic community attuned to contemporary digital cultures and practices.

7. Author contributions

This article is the result of collaborative efforts among the authors and the Yo-Media project working group. Alessandra Carenzio wrote Section 4.2, 5.2 and 6, Stefano Pasta wrote Section 1, Maria João Atunes and Oksana Tymoshchuk authored Section 2, Ruth S. Contreras-Espinosa and Jose Luis Eguia-Gomez wrote Section 3.1, 4.1 and 5.1, Oksana Tymoshchuk, Frederico Proença, Ana Passos contributed to Section 3.2. We appreciate the valuable contributions and insights provided by each member of the team.

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Exploring Elli's World: A case study on students' performance in media literacy tasks and teachers' perceptions

Esplorando il mondo degli Elli: uno studio di caso sulle performance degli studenti e le percezioni degli insegnanti in compiti di alfabetizzazione ai media

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ABSTRACT This study investigates a game-based learning approach to enhance reading comprehension through multiple texts, emphasizing the importance of critical media engagement for students' academic success. Involving 155 students (F=83, Mean age=10.8, SD=1.3) from 5th (n=44), 6th (n=44), and 7th grades (n=65), along with 33 teachers who participated in a voluntary survey, the research aimed to assess students' performance in Media Literacy tasks during four sessions of the videogame "Elli's World". Results indicated performance improvements from Session 1 to Session 3, followed by a decline in Session 4, suggesting potential fatigue. Although the class variable did not have a statistically significant impact on score increases, students' performance evolved differently over time depending on the class: younger students benefited from the game-based environment, whereas older students may respond better to shorter sessions. Although teachers expressed moderate satisfaction with the intervention, they reported no significant changes in students' behaviour, highlighting the need for diverse instructional strategies and ongoing professional development to better align educational initiatives with classroom realities.

KEYWORDS Game-Based Learning; Media Literacy; Intertextual Integration; Primary and Lower Secondary School; Serious Game.

SOMMARIO Questo studio indaga un approccio di apprendimento basato sul gioco per migliorare la comprensione della lettura attraverso testi multipli, sottolineando l'importanza di un coinvolgimento critico con i media per il successo accademico degli studenti. Coinvolgendo 155 studenti (F=83, età media=10,8, DS=1,3) delle classi 5^ primaria (n=44), 1^ (n=44) e 2^ secondaria primo grado (n=65), insieme a 33 insegnanti che hanno partecipato a un sondaggio volontario, la ricerca mirava a valutare le prestazioni degli studenti in compiti di alfabetizzazione ai media durante quattro sessioni del videogioco "Il mondo degli Elli." I risultati hanno mostrato un miglioramento delle prestazioni dalla Sessione 1 alla Sessione 3, seguito da un calo nella Sessione 4, suggerendo l'influenza di fattori motivazionali esterni e di fatica. Sebbene la variabile classe non

abbia avuto un impatto statisticamente significativo sull'aumento dei punteggi, le performance degli studenti si sono evolute in modo diverso nel tempo a seconda della classe: gli studenti più giovani hanno beneficiato dell'uso dell'app educativa, mentre gli studenti più grandi potrebbero necessitare di sessioni di gioco più brevi. Sebbene gli insegnanti abbiano espresso una soddisfazione moderata per l'intervento, non hanno riportato nessun cambiamento significativo nel comportamento degli studenti, evidenziando la necessità di strategie didattiche diversificate e di un continuo sviluppo professionale per allineare meglio gli interventi educativi con le realtà scolastiche.

PAROLE CHIAVE Apprendimento Basato sul Gioco; Alfabetizzazione ai Media; Integrazione Intertestuale; Scuola Primaria e Secondaria di Primo Grado; Serious Game.

1. Introduction

In an increasingly digital world, in which the advent of digital technologies has transformed how information flows and how people connect and interact among themselves (Castells, 2000), the ability to critically engage with media and information is essential for students' academic success and personal development as future citizens who need to understand how economic, political and cultural life work in a networked society (Castells, 2000; Hobbs, 2006). As educational institutions strive to prepare learners for the complexities of communication in our modern society, the integration of Media Literacy (ML) into school curricula has gained significant attention. In our societies digital and physical realities are intertwined, and information and knowledge are constantly generated, processed and exchanged through various media in the so called "infosphere" (Floridi, 2014). Thus, individuals are part of an information ecosystem in which boundaries between online and offline, virtual and real, are increasingly blurred in the so called "onlife" (Floridi, 2015). The integration of ML into curricular activities in schools could foster critical thinking skills and empower students to navigate diverse information sources effectively and responsibly. Concurrently, advancements in educational technology, particularly through digital game-based learning interventions, offer innovative methods for enhancing learning experiences and developing essential cognitive and affective-motivational skills. In this scenario, serious games have gained more attention: these tools are not designed primarily for fun or entertaining, whereas they aim to educate, train and support behavioural change (Michael & Chen, 2006).

This research study investigates an innovative approach to enhancing reading comprehension through the integration of multiple texts while playing a serious game. Recognizing the potential of this educational approach, the study explores the feasibility of a digital game-based intervention designed to foster students' ability to navigate and synthesize information from diverse sources. By examining the design elements of the game, teachers' perceptions and student outcomes, this study aims to contribute to the growing body of evidence supporting the use of game-based interventions for educational purposes.

2. State of the art

The integration of ML in schools is increasingly recognized as essential for preparing students to navigate a complex information landscape. ML encompasses the ability to access, analyse, evaluate, create, and act upon various forms of communication, equipping students with the skills necessary to discern credible sources from misinformation (Lipkin, 2021). ML can be integrated into educational curricula through three main approaches: as a disciplinary subject, a cross-curricular theme or a blended

model. As a standalone discipline, it emphasizes critical analysis, evaluation, and the creation of media texts, often focusing on media production skills and theoretical frameworks (Hobbs, 1998). Alternatively, a cross-curricular approach integrates ML concepts into subjects such as history, science, and literature, offering contextual diversity but potentially risking a loss of focus if not effectively managed (Kress, 1992). The blended model combines these strategies, integrating dedicated ML modules with cross-disciplinary applications to balance depth and practical relevance. This adaptable framework allows schools to align ML instruction with their educational objectives while addressing the complexities of a media-rich society (McDougall, 2010; Hobbs, 1998).

The ability to critically analyse, evaluate and create media are key components of ML and has become essential in today's digital age. To cultivate all these skills, Media Education (ME) provides a structured framework in schools to promote media competence, encouraging conscious and responsible media use and integrating media in teaching (Rivoltella, 2001). Scholars and media educators highlight the expansive scope of Media Literacy and Media Education, which extends beyond developing critical thinking skills to include a deeper commitment to fostering citizenship education. As Rivoltella (2001) and Buckingham (2006) point out, these fields empower individuals not only to analyse, evaluate, and create media but also to engage with its social, political, and cultural dimensions. By fostering digital literacy, ethical awareness, and critical autonomy, ME prepares students for active participation in democratic processes and encourages them to address contemporary societal challenges. Hobbs (2006) further underscores this connection, viewing ML as a pathway to cultivating reflective, informed citizens capable of contributing to a more equitable and participatory society. Research indicates that structured media literacy programs can positively impact students' critical analysis skills and attitudes toward media consumption (European Commission, 2022). Among interventions integrating ML into school curricula, the ones aimed at enhancing self-regulation in media and information literacy processes have shown promise. These programs often involve active teaching methods that engage students in evaluating media messages and understanding their implications (Sadeghi et al., 2015). Media literacy can be implemented through games (Pang & Pang, 2022), using either "game-based" or "gamified" approaches. Game-based learning (GBL) can be defined as a learning method which integrates actual games into the learning environment (Chang & Hwang, 2020), thus using games designed with educational purposes to facilitate learning through gameplay. Gamification can be defined as "the use of game design elements in non-game contexts", including elements that enable students' self-regulation as progress bars, badges and points that ensure monitoring progress (Deterding et al., 2011).

Studies have explored the perceptions of both students and teachers regarding gamified interventions, revealing challenges in implementing approaches that train Executive Functions (EF) as tools for managing media literacy tasks (Hakala et al., 2020). EF are top-down mental processes required in complex tasks to control the implementation of cognitive processes and training interventions adopt oftentimes a gamification approach, because gamification can help sustain students' cognitive efforts required by EF and motivate students (Pineda & Buensuceso, 2023). To strengthen students' self-regulation, game-based learning has emerged as a powerful strategy for enhancing educational outcomes (Barz et al. 2024; Mao et al., 2021). In particular, digital game-based learning (DGBL) interventions promote teaching and learning processes using digital games and apps on a computer or a mobile device. Effective game design elements – such as clear objectives, immediate feedback, and engaging narratives – are crucial for fostering student motivation and learning (Gee, 2013). The results of a meta-analysis by Barz et al. (2024) support the hypothesis that DGBL interventions lead to improved learning compared with traditional teaching methods, especially for cognitive and affective-motiva-

tional outcomes. Studies included in the meta-analysis showed that, for cognitive learning outcomes, DGBLs had a significant positive impact on knowledge acquisition and recall. Interventions utilizing game-based learning approaches have been studied for various educational aims, including improving engagement and critical thinking skills among students (Mao et al., 2021).

In this game-based learning scenario, teachers' perceptions of these tools also play a significant role; their values and beliefs about game-based learning can influence implementation success (Kapp, 2012).

The innovation of our approach lies in the use of an educational app (Elli's World) designed to train complex cognitive tasks in a digital environment, in which gamified elements sustain students' motivation and engagement, while also conducting a study to evaluate the efficacy of a game-based learning intervention from an evidence-based research perspective. Through an integrative approach, including media literacy, game-based learning intervention, gamification and self-regulation, we aim to enhance students' capabilities in managing information critically and effectively.

3. Design and development of a gamified app to train EF and Media Literacy

The app "Elli's World" follows the journey of a little Ello (it stands for "cervEllo" that it's "brain" in Italian), a young brain guided by Big Ello through various city districts, engaging players in activities that enhance EF through gamified coding and literacy tasks. Students navigate an urban environment completing tasks to earn star points based on success and time, motivating self-regulation. Daily sessions conclude with a points summary.

The game includes a Media Literacy (ML) district, aimed at enhancing students' ability to comprehend and integrate multiple texts by supporting the cognitive processes involved in the task. A video sets the context for writing an article on one of four themes (bottled versus tap water, animal versus lab-grown meat, electric versus gasoline-powered cars, and the use of robots in medicine), using preselected texts. The session kicks off with a coding activity, followed by questions aimed at assessing students' prior knowledge. Students are later asked to arrange ten steps of an article outline in the correct order (see Figure 1).

At this stage, students are presented with the titles, previews, and authors of eight texts developed ad hoc. Students are required to evaluate these previews (2 highly relevant, 2 moderately relevant, 4 irrelevant), assigning scores (2, 1, or 0). For this relevance judgement task, students should focus on the research topic and should identify the most relevant comprehensive titles. Irrelevant previews require justification (e.g., complex text, unhelpful preview). Final feedback compares their answers to correct scores.

For the following steps, student will use only texts from the four correct previews. Once this phase is completed, students are tasked with estimating the time, in minutes, required to complete the following activities.

The ability to make accurate time estimate is crucial in everyday life and aids students in self-regulating during tasks and daily activities. At the end, a countdown timer on the top of the screen allows students to monitor their activity. If time runs out, students can still finish their work but will lose the time estimate star. This affects only the total points shown at the end of the session, but without consequences for the course of the game.

Before viewing full texts, students predict how many snippets they will select from each text (out of a total of 20 snippets), while only showing the relevant previews. This expectation can be confirmed or adjusted when students access the complete documents. The goal of this phase is to encourage students

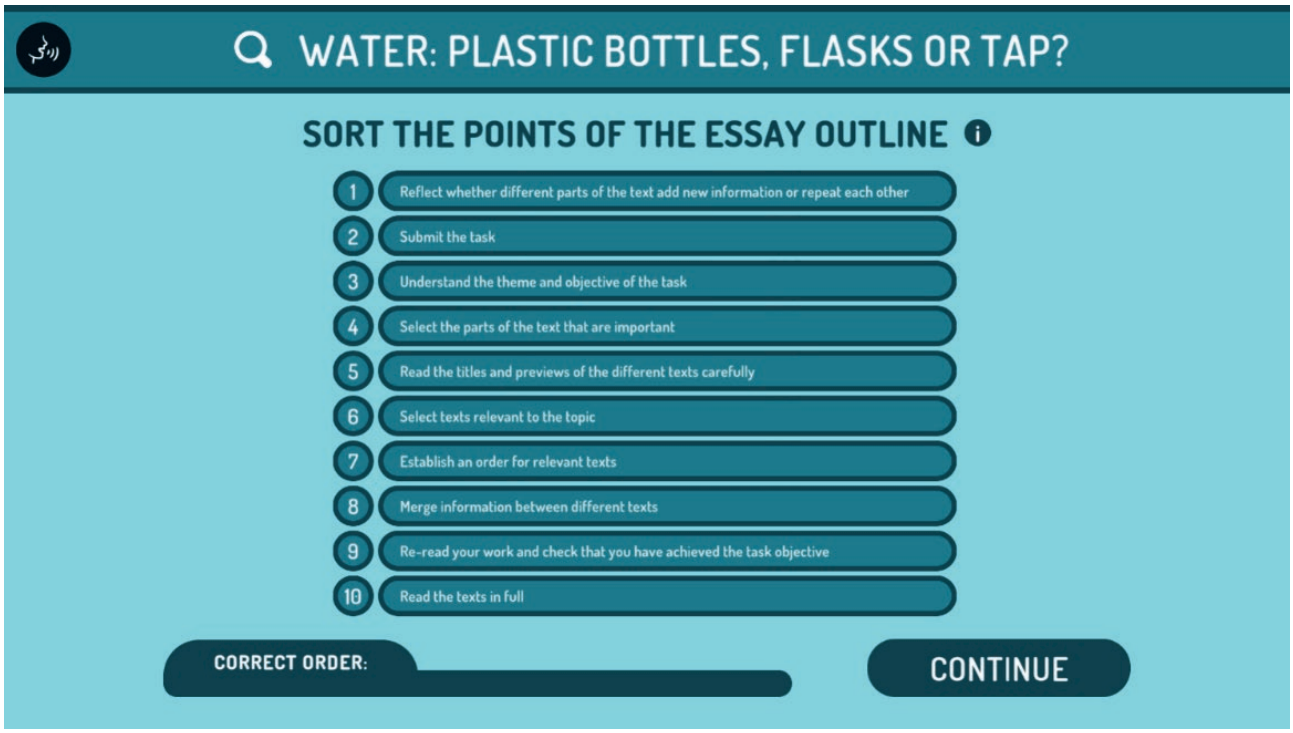

Figure 1. Screenshot of the essay outline task.

Figure 2. Screenshot of the relevance judgment task.

Figure 3. Screenshot of the production task.

to anticipate what they will find as they approach various sources of information, knowing only some features but not all content.

Once the complete texts with their relevance scores are displayed, students should identify the most relevant and informative snippets from each text to compile in their virtual notebooks. Each text has been specifically designed to contain two highly relevant snippets that yield maximum points if selected, along with two non-relevant snippets worth 0 points and other moderately relevant snippets with a score of 1.

During the article production phase, students rearrange their selected snippets within their virtual notebooks. They can connect these text snippets using cards featuring various types of conjunctions (coordinating, adversative, correlative, causal, temporal, conditional, consecutive, concluding). Additionally, during the revision, students can leverage superpowers gained while playing Elli's World for drafting assistance. Specifically, the interference control and response inhibition button suggest removing repeated or irrelevant parts; the working memory button helps ensure no important information is overlooked; and the cognitive flexibility button encourages students to verify the order of snippets for coherence.

Next, from a list of proposed keywords, students must select three that best represent their article's theme and identify the most fitting title. In the final stage, they are asked metacognitive questions designed to explore their personal perception of task difficulty. They will also choose one or more pieces of advice to share with future young Elli who may face similar challenges in article writing.

4. Aims

The present study aims at exploring the feasibility of a game-based training to understand and train processes that are needed in media and information literacy. Moreover, the study aims to inves-

tigate the perceptions of teachers regarding implementing a complex ML task through an educational app. We aim to assess:

RQ1) How do students perform on the gamified media learning activities?

RQ2) How do teachers perceive the game-based intervention and what are the challenges from their points of view?

This study has exploratory and descriptive aims, and the methodology section provides context by detailing the larger study from which these data were derived.

5. Methodology

5.1. The context

The subgroups of participants (teachers and students) described in this reported research is part of a larger population of 528 students and 14 teachers which were involved in the EMILE (Empowering schools in self-regulation of Media and Information Literacy processes) project, funded by the European Media and Information Fund, managed by the Calouste Gulbenkian Foundation and coordinated by the University of Florence with partners Anastasis Social Cooperative, Tampere University, and the Romanian-American University. The EMILE project was designed to empower adolescents' critical (digital) reading competence by supporting the underlying cognitive processes and to provide professional development to support teachers' competence in critical reading education. The University of Florence was responsible for the design and implementation of "Elli's World-Media Literacy", an update of the previous validated educational intervention through the "Elli's World" app. The EMILE project involved two comprehensive schools in Tuscany, working with primary and secondary schools, and in this study, we described sociodemographic data from one of the two schools. Feasibility and satisfaction data from teachers from the other school were incomplete and could not be considered for an integrated analysis of students' performance and teachers' perceptions. The larger intervention was a randomized control trial aimed at verifying the efficacy of an adaption of the game to train cognitive functions that are needed in critical reading and therefore support students' self-regulation of media and information literacy processes.

5.2. Participants

In September 2023, 2 schools were recruited to participate in the project. After obtaining authorization from the school administrators and informed consent from the parents, the intervention began in October 2023 and concluded in December 2023.

Participants in this restricted population were 155 (F=83, Mean age=10.8, DS=1.3), attending 5th grade (2 classes, n=44), 6th grade (2 classes, n=44) and 7th grade (2 classes, n=65)[1]. Teachers involved in the feasibility and satisfaction survey were 33, as answers were given on a voluntary basis by all teachers, across subject areas and special education, at both primary and secondary school, teaching in the classrooms involved with the game-based training.

[1] In the Italian school system, 5th grade corresponds to the final class of primary school, while 6th and 7th grades are the first two classes of middle school.

5.3. Materials

5.3.1. Students' performance in the Elli's World app

To describe a more complete picture of students' engagement with the app, in the larger project students' satisfaction and enjoyment in the training and feedback of feasibility were assessed through a survey designed *ad hoc* with 11 statements, using a 5-point Likert scale (1= not all; 5= very much). The reliability of the scale was assessed using Cronbach's alpha. The analysis yielded a Cronbach's alpha of 0.667, indicating an acceptable but moderate level of internal consistency. Although this value is below the commonly accepted threshold of 0.70, it may still be considered adequate for exploratory research (Hair et al., 2010).

The app allows to collect data through learning analytics techniques referring to students' performances in several ML tasks. For this study, we were interested into describing two specific tasks: the production task and the title selection task.

For the production task, the app calculates a relevance score based on the cumulative relevance scores of each snippet used in the text. During the production phase, students are presented with the four most relevant texts pertaining to the overall topic and may select their preferred snippets from each of these sources, with a maximum limit of 20 snippets in total. Each snippet has an assigned score already established. Consequently, when students make their selections, the system automatically records the corresponding relevance scores (2, 1, or 0). This approach allows for a measurement of relevance for each written text produced. Each relevant text has a maximum relevance score of 8, derived from the inclusion of 2 highly relevant snippets (total score of 4), 4 relevant snippets (total score of 4), and 2 irrelevant snippets (total score of 0). Consequently, the maximum score for the production task for each research topic is 32 points (8 points multiplied by 4 texts).

For the title selection task, students should select the most appropriate title for their written text, choosing from four options, where only one is the most suitable, as it represents the comparisons of different opinions. Two of the other options don't refer to the research topic, while one title focuses only on one side of the comparison. For the coding system, 1 point is assigned for the correct title. The maximum score a student can reach after the four sessions is 4 points.

5.3.2. Teachers' perceptions

Teachers' feasibility and satisfaction survey was structured in two parts and administered at different times.

Section 1 was administered to one teacher for each class involved in the training, at the final session of the game. Answers to the following statements, using a 5-point Likert scale (1= not all; 5= very much), were collected from 7 teachers.

Question number 11 was open-ended and ask for teachers' opinion on the app: "Now we ask you to kindly provide us with some information for the improvement of the app. If you could change anything, what changes would you suggest?"

Section 2 of the questionnaire was administered 5 months after the conclusion of the intervention to all the teachers working in the classrooms involved in the training. Answers from 33 teachers were collected. The questions (Yes/No, judgment on a 10-points Likert scale and justification open-ended) are shown in table 2.

Table 1. Items of Section 1 from teachers' feasibility and satisfaction's survey.

Items
1. I am satisfied to have taken part in the enhancement project.
2. I would recommend this training to other teachers.
3. I would do this training again if there was a chance.
4. I have noticed improvements in pupils' behaviour after the training.
5. I have noticed improvements in the pupils' academic performance after the course.
6. It was difficult to find 30 min per week to devote to the weekly training session.
7. It was difficult to find 30 minutes twice a week to devote to the weekly training session.
8. It was difficult to find 1 hour twice a week to devote to the ML training session.
9. I would have liked to be more involved in the students' video game sessions.
10. I would like to receive specific training in the use of the app "Elli's world" to propose it independently to my students.

Table 2. Items of Section 2 from teachers' feasibility and satisfaction's survey

Items
1. Do you find the project interesting?
2. Briefly justify your previous answer.
3. Do you think the project is useful from an educational perspective?
4. Would you use an app like "Elli's world" in class with your pupils?
5. How do you assess your level of knowledge of Executive Functions prior to the training?
6. How do you assess your level of knowledge of Executive Functions after participating in the training?
7. Do you think you are aware of the levels of your pupils' EF skills?
8. Do you think it is useful from an educational perspective to be aware of the levels of your pupils' EF skills?
9. Briefly justify your previous answer.
10. At the end of the training, did you notice any behavioral changes in your pupils?
11. If you have detected changes, please give some examples.
12. Has this experience changed something in your way of teaching?
13. Which critical issues and challenges did you notice within the training?
14. Would you like to add some suggestions to improve the activity and the training?

5.4. Procedure

Before the start of the training with the app, teachers of Intervention Group participated in two meetings with the researchers, where they were instructed on the objectives, purposes, structure and methods of the intervention.

Regarding the larger project's objective to assess training's efficacy, pre- and post-training assessments of Executive Functions and Reading Comprehension (standardized tests) and Intertextual Integration (test designed ad hoc based on previous research) were conducted in the first and last weeks for both Intervention and Control Group.

The project was conducted entirely during school hours with the support of researchers and was designed to be highly inclusive, allowing all students in the class to participate, including those with neurodevelopmental disorders or disabilities. During the first four weeks, the videogame sections focused on EF training were covered in two 30-minute sessions per week. The final two weeks of train-

ing in the ML district involved two 1-hour sessions per week. At the end of the training, students' questionnaire and teachers' survey were administered, paper-and-pencil and digital way respectively.

5.5. Data analysis

Data from teachers' survey (both sections) and learning analytics data from two tasks (production and selection of correct title) from 102 sessions with the app (the incomplete game sessions were not included in the analysis for this case study) were processed and analysed (RQ1). The analysis of descriptive statistics aims to compare maximum scores to assess performances in two tasks, as well as to evaluate descriptive performances across different school levels. In addition, a content analysis was employed to classify the qualitative data from open-ended questions within the teachers' survey to quantitative data. This systematic process produced a numerical summary of the answers set for RQ2.

6. Results

6.1. Research Question 1: How do students' performance on Media Literacy tasks evolve over time?

Initial descriptive statistics were conducted and analysis of the normality of the distribution showed that the production index for all the four sessions was normally distributed (skewness [-.59; 0.17]; kurtosis [-.09; 1.15]), while 3 out of 4 choose of correct title variables were normally distributed (skewness [.3; 0.12]; kurtosis [-1,93; 0.08]).

The following figures show how performances on the two variables (Production and Title selection tasks) changes over time. Estimated marginal means , including 95% confidence interval for each session, are shown. As Figure 4 suggests, in the production task students perform progressively better through Session 1 to 3, showing higher points of production, suggesting that they become more aware in the selection of relevant snippets. From Session 3 to 4 points of production slightly drop, but per-

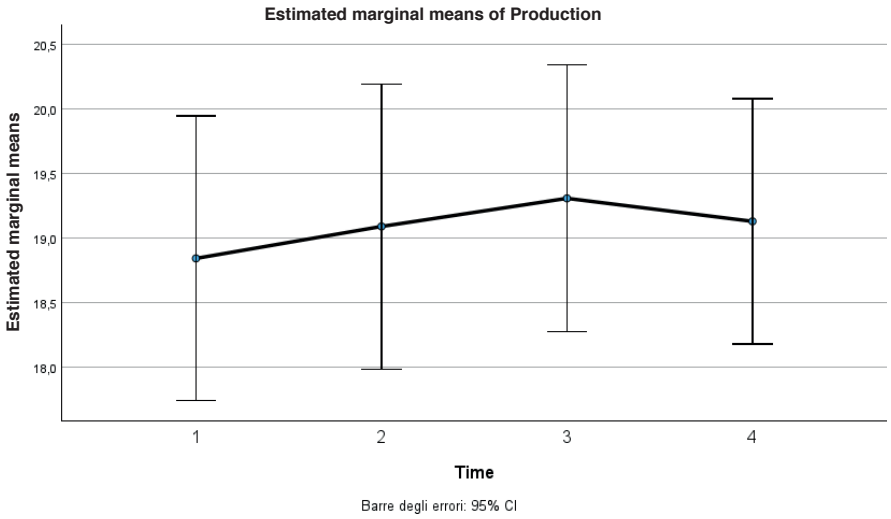

Figure 4. Students' performance data on the **Production task** over time (estimated marginal means; 95% CI).

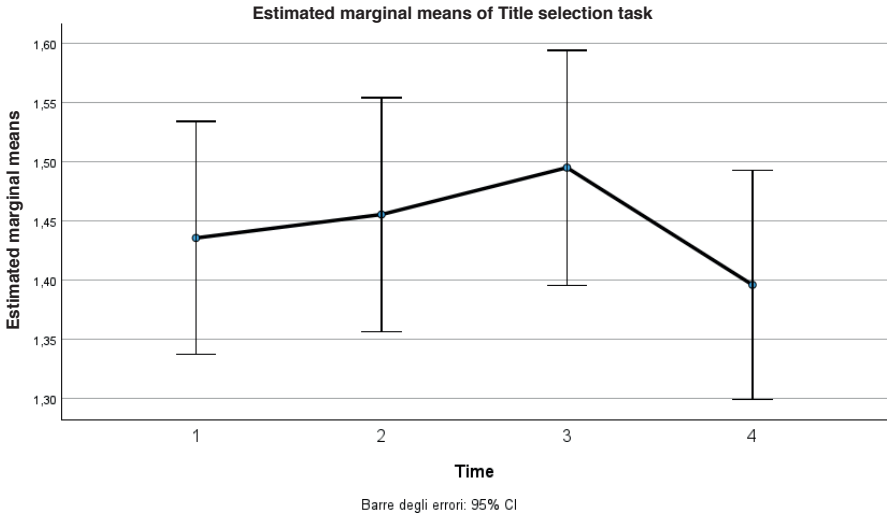

Figure 5. Students' performances on the **Title selection task** over time (estimated marginal means; 95% CI).

formances from the beginning of the training (M=18.84; DS=5.59) towards the final session (M=19.13; DS=4.81) register higher scores. Comparing to the maximum score for this task (32 points), estimated marginal means over the four sessions were significantly below, slightly above the half score.

Moreover, as Figure 5 suggests, initially there is a gradual increase in the marginal means from Session 1 to Session 2, followed by a more pronounced rise that peaks in Session 3. A higher estimated marginal means suggests that more students perform better on the task, as the coding system assigned 1 point for incorrect title and 2 for correct title. However, after reaching this peak, there is a significant decline between Sessions 3 and 4, with the marginal means falling below the levels observed in Session 1, indicating less students correctly selected the title in the last sessions. This pattern, with a final decline, may suggest factors such as participant fatigue, reduced efficiency, or alterations in task conditions affecting the performances of students towards the end of the training.

To compare the estimated marginal means in relation to Production and Title selection tasks' performances across three distinct class, a hierarchical linear regression was conducted, showing that the grade variable did not have a statistically significant impact on growth in production across the four time points (Wilks'λ= .95, F= .84, df= 6, 196; p= .54, η2= .03) neither in title selection across the four time points (Wilks'λ= .97, F= .48, df= 6, 196; p= .82, η2= .02). As no significant differences attributable to the class were found, the following differences across grades are presented descriptively.

Figures 6 illustrates the estimated marginal means of Production task over four sessions across three distinct classes (5^{th-} 6^{th}-7^{th} grades). As Figure 6 suggests, 6^{th} grade begins at the highest level (M=19.18; DS=4.78) and demonstrates a steady increase, peaking in Session 3 (M=20.27; DS=4.02) before experiencing a slight decline in Session 4. In contrast, 7^{th} grade shows greater stability, maintaining marginal means around 19 throughout the sessions, with a gradual increase leading to Session 3 (M=19.40; DS= 5.76) followed by a decrease in Session 4 (M= 18.55; DS=5.59). 5^{th} grade starts at a lower level (M=18.50; DS=6.19), experiences a dip between Sessions 1 and 2 (M=17.77; DS= 6.77), but recovers by Session 4. These patterns suggest that 6^{th} grade consistently performs the best, while 5^{th} grade exhibits the most variability in performance.

Figure 7 illustrates the estimated marginal means for the Title selection task. In this analysis, a higher estimated marginal means suggests that more students perform better on the task, as the cod-

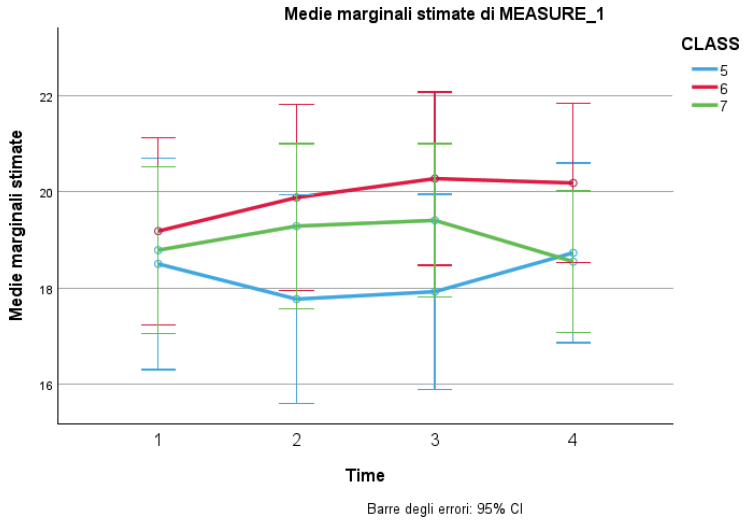

Figure 6. Students' performance in time and between class on the Production task (estimated marginal means; 95% CI).

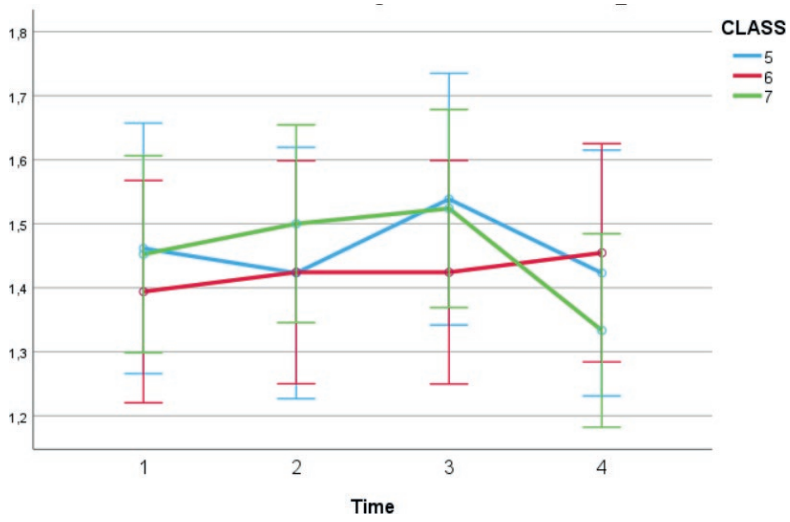

Figure 7. Students' performance in time and between classes on the Title selection task (estimated marginal means; 95% CI).

ing system assigned 1 point for incorrect title and 2 for correct title. 5th grade demonstrates significant fluctuations, experiencing a decline from Time 1 (M=1.46; DS=0.51) to Time 2 (M=1.42; DS=0.50), followed by a sharp increase that peaks in Session 3 (M=1.54; DS=0.51), and then a steep drop in Session 4 (M=1.42; DS= 0.50). In contrast, 6th grade maintains a more stable pattern, exhibiting a gradual increase in means across the four sessions, which suggests consistent performance. 7th grade shows an upward trend from Session 1 (M=1.45; DS= 0.51) to Session 3(M= 1.52; 0.51), peaking in Session 3 before experiencing a sharp decline by Session 4. These patterns indicate variability in performance across the classes, with 6th grade exhibiting the most stability and an increase from session 1 to 4 in the number of students who performed well on the task, while grades 5th and 7th display more dynamic changes, particularly notable declines following their peaks in Session 3. This suggests that

towards the final session, more students of 5th and 7th grades perform worse on the task than in the first session.

6.2. Research Question 2: How do teachers perceive the gamified intervention and what are the challenges from their points of view?

For the first section of the survey, answers to 10 items using a 5-point Likert scale were collected from 7 teachers and means and standard deviations for each item were calculated to create the following graph in figure 8. Teachers were satisfied to have taken part in the training (M=3.4, DS=0.5), would suggest other colleagues to participate (M=3, DS=0.6) and would do the intervention again (M=3, DS=0.8), even if they didn't notice any changes in their students' behaviours or academic performances after the training.

Answers to the open-ended question (Item 11) were 2 out of 7 and were referred to the need of paper and pencil material ("*I'd like to add some non-computerised activities to work with in class")* and to the need of more clarity to explain how the production phase works ("*I think more clarity is needed in the part concerning the composition of a text with sentences extrapolated from other texts with the same subject matter*").

Regarding the second section of the survey administered 6 months after the conclusion of the training, answers from 33 teachers were collected and frequencies were calculated for Yes or No questions and judgments on a 10-points Likert scale. For this study, only frequencies to a few items are shown in Figure 9 (Items 1,2,3,4).

For the analysis of the open-ended questions in the delayed survey, answers were read, and clusters of topics were identified, to calculate the frequency of each cluster. When teachers were asked to justify their answers to why they found or didn't find the project interesting, they valued it positively because they thought it stimulated students' motivation (30%) and students' participation and interest (30%), also because they gave importance to research assumptions and methodology (25%), and the innova-

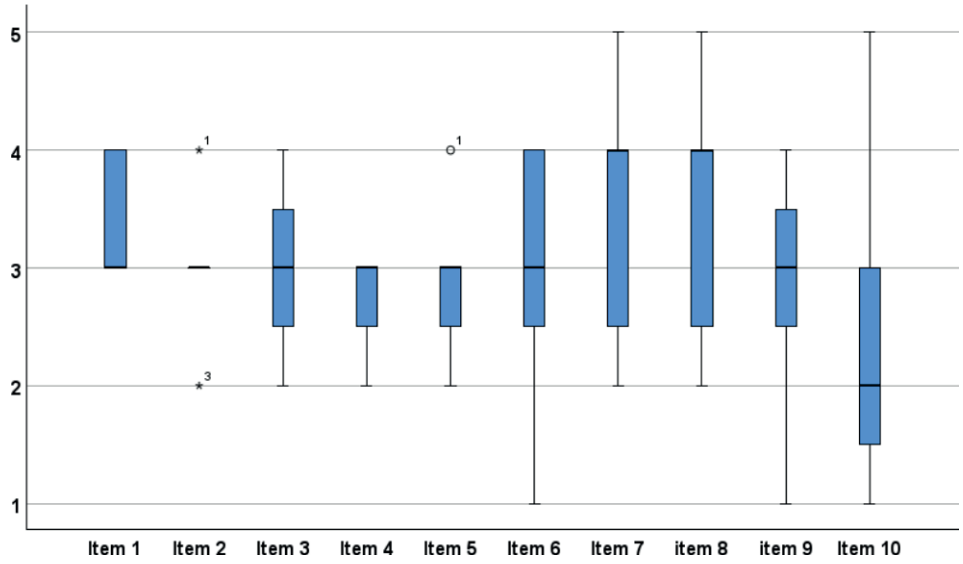

Figure 8. Boxplot of responses to Likert scale, highlighting the median, interquartile range, and the presence of outliers.

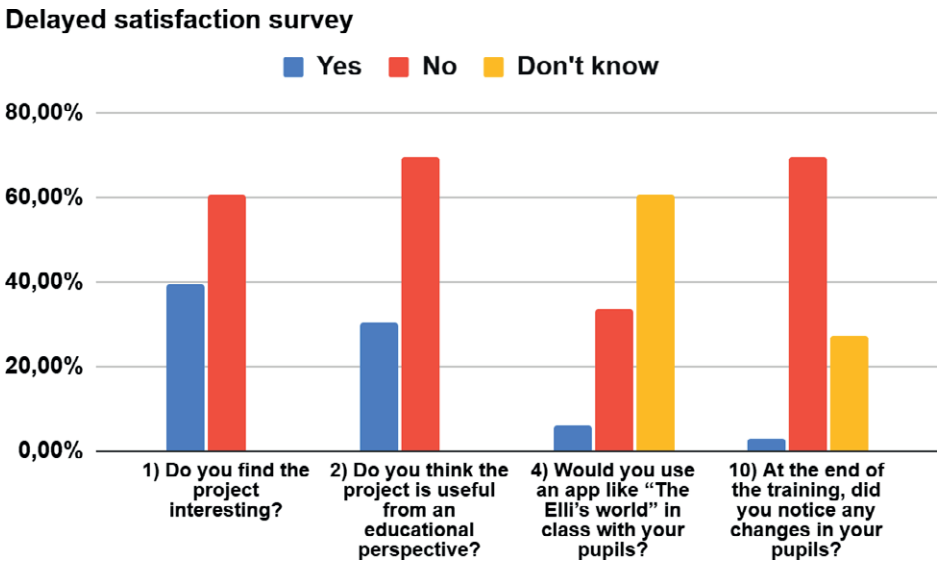

Figure 9. Bar plot of teachers' answers on items 1,2,4 and 10.

tive methodology used with the gamified app (15%). Teachers which found the project not interesting didn't justify their answer.

Regarding the question "Please identify which critical issues you may have encounter", most of them identified multiple reasons, including lack of teacher training (42.4%), excessive duration of training (30.3%) and excessive use of technology (18.2%). The most critical answers are the ones referring to a disbelief in the project's usefulness (33.3%).

7. Discussion

In our digital world, the ability to critically engage with media and information is essential for students' academic success and personal development. This research study investigates an innovative approach to enhancing reading comprehension through the integration of multiple texts within a digital game-based learning environment.

The first research question examined student performance in Media Literacy (ML) tasks – text production and title selection – across four sessions of the serious game Elli's World. Analysis revealed progressive improvement from Session 1 to Session 3, indicating increased awareness in selecting relevant snippets. However, a slight decline in Session 4 raises questions about factors like fatigue, task conditions, or motivational influences. Despite progress, performance remained below the maximum score in the production task, highlighting students' difficulty identifying the most relevant text parts for research-related tasks.

Performance trends varied by grade. Sixth graders showed steady improvement, while seventh graders initially improved but experienced a sharp decline. Fifth graders performed best initially but exhibited the most significant drop-off by Session 4. These results suggest younger students initially struggle with intertextual integration but benefit from gamified environments that sustain motivation throughout training. In contrast, older students may require shorter sessions to mitigate fatigue or external distractions. Findings align with research framing ML as an adaptive dynamic process rather

than a static skill (Potter, 2004; McDougall, 2010). In a media-saturated society, individuals must continually develop critical and creative media engagement skills responsive to diverse contexts. Students need training tailored to their cognitive abilities, age, and capacity for active participation to foster creativity and adaptability.

The second research question explored teacher perceptions of the intervention and training challenges. Survey responses from seven teachers reflected moderate satisfaction but revealed no observed changes in student behaviour or academic performance post-intervention. This disconnect suggests gaps between training content and practical classroom application. Teachers expressed a need for more hands-on, non-computerized activities and clearer production phase guidance. Teacher beliefs significantly influence instructional practices and outcomes (Pajares, 1992), yet barriers like their beliefs on insufficient training, excessive program duration, and over-reliance on technology hinder implementation (Loperfido et al., 2019). Teachers' scepticism about the program's utility highlights the importance of sustained support and professional development to build confidence in innovative methods. Addressing these challenges can bridge the gap between theoretical intervention design and practical classroom success.

Overall, these findings highlight the necessity to maintain continuous dialogue between educators and program developers to ensure that training initiatives, also with digital games, are aligned with classroom realities and effectively address teachers' concerns and students' needs.

8. Conclusions and Future directions

The aims of this case study were (1) to highlight how students' performances on media literacy tasks evolve over time, (2) to evaluate how teachers perceive the game-based intervention and what challenges do they experience.

Findings of the study underscore the importance of game-based learning in enhancing media literacy and reading comprehension. While student performance remained stable across sessions, further research is needed to explore factors affecting engagement and skill application. Gamified learning proves effective for cognitive and motivational outcomes, but tailoring interventions to diverse learners is crucial. Future research should integrate advanced tools like AI and mobile learning to personalize experiences (Cotton & Patel, 2019). Broader approaches addressing not only cognitive skills, but also societal challenges are necessary to cultivate informed citizens for democratic participation (Hobb, 2006).

Teacher engagement challenges, linked to limited knowledge and self-efficacy, highlight the need for professional development on integrating digital and serious games into curricula (Sailer & Homner, 2019). Research should explore leveraging app data to inform teaching and optimize strategies for diverse demographics (Barz et al., 2023; Koivisto & Hamari, 2019). Longitudinal studies are essential to examine the impact of game types, elements, and moderating factors on learning outcomes (Nicolaidou et al., 2019). Collaboration among educators, researchers, and developers can ensure innovative, evidence-based interventions (Fang et al., 2019; Zainuddin et al., 2020).

Furthermore, emphasizing intertextual integration early in education fosters critical skills for navigating complex information. Findings reveal students' difficulty in identifying relevant text sections, stressing the need for interventions that train them in relevance assessment (McCrudden & Schraw, 2007). Game-based learning effectively engages younger students in complex tasks, such as judging relevance across texts, but explicit instruction on criteria is essential for improving outcomes in digital environments.

9. Author contributions

CT and CP contributed to the conception of the study and organization of the database. AS contributed to the organization of the database and the intervention in schools. CB contributed to the conception and design of the intervention. SDR contributed to the organization of the database, the intervention in school and the writing of the manuscript. CT contributed to the writing of the manuscript. All author contributed to manuscript revision, read, and approved the submitted version.

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Crafting knowledge *block by block*: A systematic review on the educational potential of Minecraft in schools

Costruire il sapere *un blocco alla volta*: una revisione sistematica sul potenziale educativo di Minecraft nelle scuole

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ABSTRACT The integration of digital technologies in education has led to innovative pedagogical approaches, with the videogame Minecraft emerging as a versatile platform for game-based learning. This systematic review examines recent literature on Minecraft's educational applications in formal classroom settings. The study aims to evaluate Minecraft's integration into school curricula, exploring its benefits, challenges, and effective implementation strategies. A qualitative synthesis of 18 peer-reviewed articles published between 2019 and 2024 was conducted, covering diverse educational contexts from kindergarten to secondary schools across various subjects. Findings indicate that Minecraft-based interventions can enhance spatial thinking, foster creativity, improve engagement, and support the teaching of abstract concepts. However, successful implementation requires careful consideration of curriculum alignment, assessment methodologies, and teacher training.

KEYWORDS Minecraft; Game-Based Learning; Skill Development; Formal Education; Educational Technology.

SOMMARIO L'integrazione delle tecnologie digitali nell'istruzione ha portato ad approcci pedagogici innovativi e il videogioco Minecraft è emerso come una piattaforma versatile per il game-based learning. Questa revisione sistematica esamina la letteratura recente sulle applicazioni educative di Minecraft in ambienti scolastici formali. Lo studio mira a valutare l'integrazione di Minecraft nei programmi scolastici, esplorandone i benefici, le sfide e le strategie di implementazione efficaci. È stata condotta una sintesi qualitativa di 18 articoli peer-reviewed pubblicati tra il 2019 e il 2024, che coprono diversi contesti educativi, dalla scuola dell'infanzia alla scuola secondaria di secondo grado, in varie discipline. I risultati indicano che gli interventi basati su Minecraft possono migliorare il pensiero spaziale, favorire la creatività, migliorare il coinvolgimento e rappresentare un valido strumento per l'insegnamento di concetti astratti. Tuttavia, un'implementazione di successo richiede un'attenta considerazione dell'allineamento del curriculum, delle metodologie di valutazione e della formazione degli insegnanti.

PAROLE CHIAVE Minecraft; Game-Based Learning; Sviluppo di Abilità; Educazione Formale; Tecnologie per l'apprendimento.

1. Introduction

The advent of the digital revolution has led to a profound transformation across all sectors of society, with education being no exception (Selwyn et al., 2020). This technological upheaval has created a necessity to reevaluate traditional teaching methodologies (Ferdig et al., 2020). As digital technologies permeate every aspect of modern life, educational institutions are compelled to adapt their curricula and instructional strategies to prepare students for an increasingly digitalized world (Williamson et al., 2020). This digital metamorphosis has altered the way information is accessed and disseminated, while at the same time reshaping the very nature of learning itself, fostering new forms of engagement and interaction within educational contexts (Rapanta et al., 2020).

In response to this evolving reality, educators and researchers are focusing their attention more than ever towards educational frameworks that are able to harness the possibilities granted by digital technologies, starting with game-based learning and digital game-based learning (Bado, 2022).

Game-based learning (GBL) refers to the use of games to support learning and education. While games have long been used for educational purposes, digital game-based learning (DGBL) has emerged in recent decades as a powerful new approach leveraging digital technologies (Zainuddin et al., 2020).

Game-based learning can be broadly defined as "an environment where learners explore, experiment, construct and learn through active engagement and fun activities" (Qian & Clark, 2016). A key feature of GBL is that it combines elements of gameplay with specific learning objectives. As Prensky (2001) describes it, GBL involves the "coming together" of serious learning and interactive entertainment.

Digital game-based learning more specifically refers to the use of digital games and gaming environments to serve educational purposes (Prensky, 2001). Mayer and Johnson (2010) propose that DGBL environments should feature a set of rules and constraints, dynamic responses to learners' actions and, eventually, appropriate challenges to promote self-efficacy, paired with gradual increases in difficulty aligned with learning outcomes.

Thus, DGBL leverages the interactive, responsive, and engaging nature of digital games to create powerful learning experiences.

Some key characteristics that distinguish game-based learning approaches include defined learning goals and objectives, challenge-based activities, rules and constraints, interactivity and responsiveness, increasing levels of difficulty, feedback mechanisms, and elements of play and entertainment (Plass et al., 2020).

Digital game-based learning environments may also incorporate additional features like multimedia elements (graphics, audio, animation), simulated environments and scenarios, adaptive difficulty and personalization, data tracking and analytics, and online/multiplayer capabilities (Subhash & Cudney, 2018).

A crucial aspect of both GBL and DGBL is maintaining a balance between educational content and gameplay elements (Plass et al., 2015).

Game-based learning approaches have been applied across a wide range of educational contexts and subject areas, such as K-12 education across subjects like math, science, language learning; higher education and professional training; medical and healthcare education and training; military and defense training; business and management education (Lameras et al., 2017).

Digital game-based learning has expanded these possibilities further, enabling more immersive simulations, adaptive learning experiences, and widespread accessibility. DGBL is used for knowledge acquisition, skill development, and attitudinal/behavioural change across diverse fields (Stewart et al., 2013).

While games have been used in education for centuries, digital game-based learning emerged in the late 20th century alongside the rise of video games and personal computing (Qian & Clark, 2016).

The past two decades have seen an explosion of interest in digital game-based learning, driven by factors like ubiquity of digital devices and gaming among youth and advances in game design and development tools (Dichev & Dicheva, 2017).

Today, digital game-based learning takes many forms, from simple educational apps to complex immersive simulations. Commercial games are also increasingly used in educational contexts (Boyle et al., 2016).

Among the myriad digital games that have been adapted for educational purposes, Minecraft stands out as a particularly influential and versatile platform. Originally released in 2011, Minecraft has become a global phenomenon, captivating millions of players across diverse age groups and demographics.

Minecraft[1], developed by Markus Persson of Mojang Studios, has become one of the most popular video games of all time, with over 100 million registered players (Thompson, 2016). As an open-world sandbox game, Minecraft allows players to explore, gather resources, craft items, and build structures in a procedurally-generated 3D world made up of block-based elements (Duncan, 2011). The game's core mechanics of mining resources and constructing objects have drawn comparisons to physical building block toys like LEGO (Thompson, 2016).

Minecraft features both single-player and multiplayer modes, with the default single-player mode combining elements of survival and construction (Duncan, 2011). Players must gather resources during the day to build shelter and craft tools, while defending against hostile mobs that appear at night. The game world is composed of different biomes and materials that can be mined and recombined to create increasingly complex items and structures (Thompson, 2016).

A key aspect of Minecraft's design is its lack of explicit objectives or tutorials, requiring players to experiment and discover the game's mechanics through trial and error (Thompson, 2016). This open-ended nature allows for significant player creativity and emergent gameplay. The game also features a "creative mode" that removes the survival elements and gives players unlimited resources for building (Duncan, 2011).

Minecraft's block-based building mechanics and 3D environments have been found to support the development of spatial reasoning skills (Carbonell-Carrera et al., 2021). Research has demonstrated that Minecraft activities can lead to improvements in mental rotation ability, a key component of spatial skills that is important in STEM fields (Carbonell-Carrera et al., 2021). The game's collaborative multiplayer features also provide opportunities for developing teamwork and communication skills (Thompson, 2016).

A significant aspect of Minecraft's popularity and longevity is its extensibility through mods (modifications) and user-generated content. Players can create custom maps, textures, and game modes to share with others (Duncan, 2011). More advanced users can modify the game's code to add new types of blocks, creatures, and gameplay mechanics (Thompson, 2016). This culture of modding and sharing has created a rich ecosystem of player-created content and fostered a strong sense of community among Minecraft players.

Minecraft's relatively simple graphics and flexible system requirements have contributed to its widespread accessibility. In order to achieve better results in terms of gaming accessibility, Minecraft's game

[1] https://www.minecraft.net/

designers provided players with the option to personalize the game experience by choosing between various settings and levels of difficulty. Furthermore, there have been efforts to render the game as enjoyable as possible for people with disabilities: the association Special Effect developed EyeMine, a "free eye-control optimised software that enables Minecraft to be played without a keyboard or a mouse".[2] The game is available on a wide range of platforms, including computers, mobile devices, and gaming consoles (Carbonell-Carrera et al., 2021). This cross-platform support, combined with its intuitive block-based mechanics, has allowed Minecraft to appeal to a broad demographic, from young children to adults (Thompson, 2016).

1.1. Aim and objective

Minecraft Education, an educational variant of Minecraft, has emerged as a significant tool in the field of educational technology. This adaptation aims to harness the engaging qualities of Minecraft for educational purposes. Since its inception, Minecraft Education has garnered attention for its potential to facilitate innovative learning experiences across various disciplines.[3]

The genesis of Minecraft Education can be traced back to the widespread adoption of Minecraft in informal learning environments. Educators and researchers observed the game's capacity to foster creativity, problem-solving skills, and collaborative learning among students. This recognition led to the development of a dedicated educational version, designed to align with curricular objectives while maintaining the core elements that made the original game appealing to learners.

Minecraft Education is characterized by several key features that distinguish it from its commercial counterpart. These include built-in assessment tools, a classroom management interface, and a library of pre-designed lessons covering subjects ranging from history and science to computer programming. The platform also supports the creation of custom content, allowing educators to tailor learning experiences to their specific pedagogical needs.

The success of Minecraft in informal contexts has prompted researchers and educators to explore its potential integration into formal education frameworks. This transition presents both opportunities and challenges. Minecraft Education offers a familiar and engaging medium through which students can interact with complex concepts in a three-dimensional environment. However, the effective implementation of game-based learning tools in traditional educational structures requires careful consideration of factors such as curriculum alignment, assessment methodologies, and teacher training (Nebel et al., 2016).

Our research question stems from all these reasons. Due to the incredible success that Minecraft has encountered in informal settings, a systematic literature review on its integration into formal education, and specifically in schools, has been carried out. The intent is to analyze whether Minecraft could be effectively integrated into school curricula, what the resulting benefits would be, what challenges would need to be addressed, and how it could be done effectively and efficiently.

This systematic review addresses four critical research questions that aim to move beyond descriptive analysis to provide actionable insights for educators and researchers while identifying critical patterns in implementation success factors. We focused on four research questions:

1) How does Minecraft's educational effectiveness vary across different student demographics and age groups, and which populations benefit most from this educational tool?

[2] https://www.specialeffect.org.uk/how-we-can-help/eyemine

[3] https://education.minecraft.net/en-us

2) Which are the emerging patterns in effectiveness across different subject areas?
3) Which are the essential teacher competencies and support structures for successful implementation?
4) Which are the primary barriers to effective implementation and the potential solutions to promote a widespread adoption of Minecraft?

2. Methodology

2.1. Search strategy

Different databases were used to search for studies for the current review. These databases included SCOPUS, Web of Science, and EBSCOhost Research Databases.

The search string consisted of three fields. The first field identified the reference methodology, game-based learning. The second field addressed the main topic of our review: Minecraft Education. A third and final keyword was added to limit our results to experiences carried out in formal education settings, from kindergarten to high school. The resulting search string was as follows: ("game-based learning" OR "GBL") AND ("Minecraft") AND ("school"). The research string was applied to titles, abstracts and keywords.

The term "school" in our search string was chosen to focus on formal education settings for students under 18 years of age. While we acknowledge that not all formal education institutions for this age group are universally termed as "schools" (some being called academies, institutes, or other locale-specific denominations), our preliminary searches indicated that "school" remains the most commonly used term in academic literature to refer to K-12 formal education institutions, even more than "formal education" itself, which, as a broader term, could have brought to the inclusion of irrelevant studies. The decision to maintain a single, specific term rather than including multiple synonyms helped maintain a clear focus on K-12 formal education while reducing the inclusion of articles from other educational contexts that were not relevant to our research scope.

The studies were double-checked and filtered by the two authors.

We focused on papers from 2019-2024 to capture recent developments in educational technology and game-based learning.

The articles were selected based on key criteria: the presence of Minecraft-based educational activities in formal education settings, an overall focus on the possible beneficial and negative effects on learning and skill development, and the existence of evidence-based outcomes obtained through case studies and data analysis. Only primary studies were included.

The papers were selected from peer-reviewed English publications. The query was run on titles, abstracts and keywords. We excluded studies outside formal school settings and those without available full texts. Articles that didn't approach the main topic through a game-based learning perspective were excluded, as were those that didn't focus on the application of Minecraft in educational environments as the principal research focus. The considerably high number of filter criteria (available full text, final publication stage, English language, last five years, peer reviewed) meant that some of the databases contained a relatively low number of pertinent studies. However, this was accounted for in the study design, and ensured that the review had a focused and precise scope. A qualitative synthesis of the most relevant information was also conducted, comparing the various publications; this was done without carrying out a quantitative analysis in the meta-analysis format.

The process of including papers in the systematic review is described in Figure 1. The initial search provided 90 papers. After the elimination of duplicates (n = 20), 78 studies consistent with the research parameters were identified. After excluding publications that were not relevant for their topic (n = 33), those that had to be excluded because of their target audience (n = 5), a scoping review, two conference proceedings, and two theoretical articles, 27 reports were sought for retrieval. The full text of six articles could not be retrieved, so 21 studies were assessed for eligibility. Eighteen of them were included in the final review, while one was excluded because of its target population and two others were deemed irrelevant to the research questions.

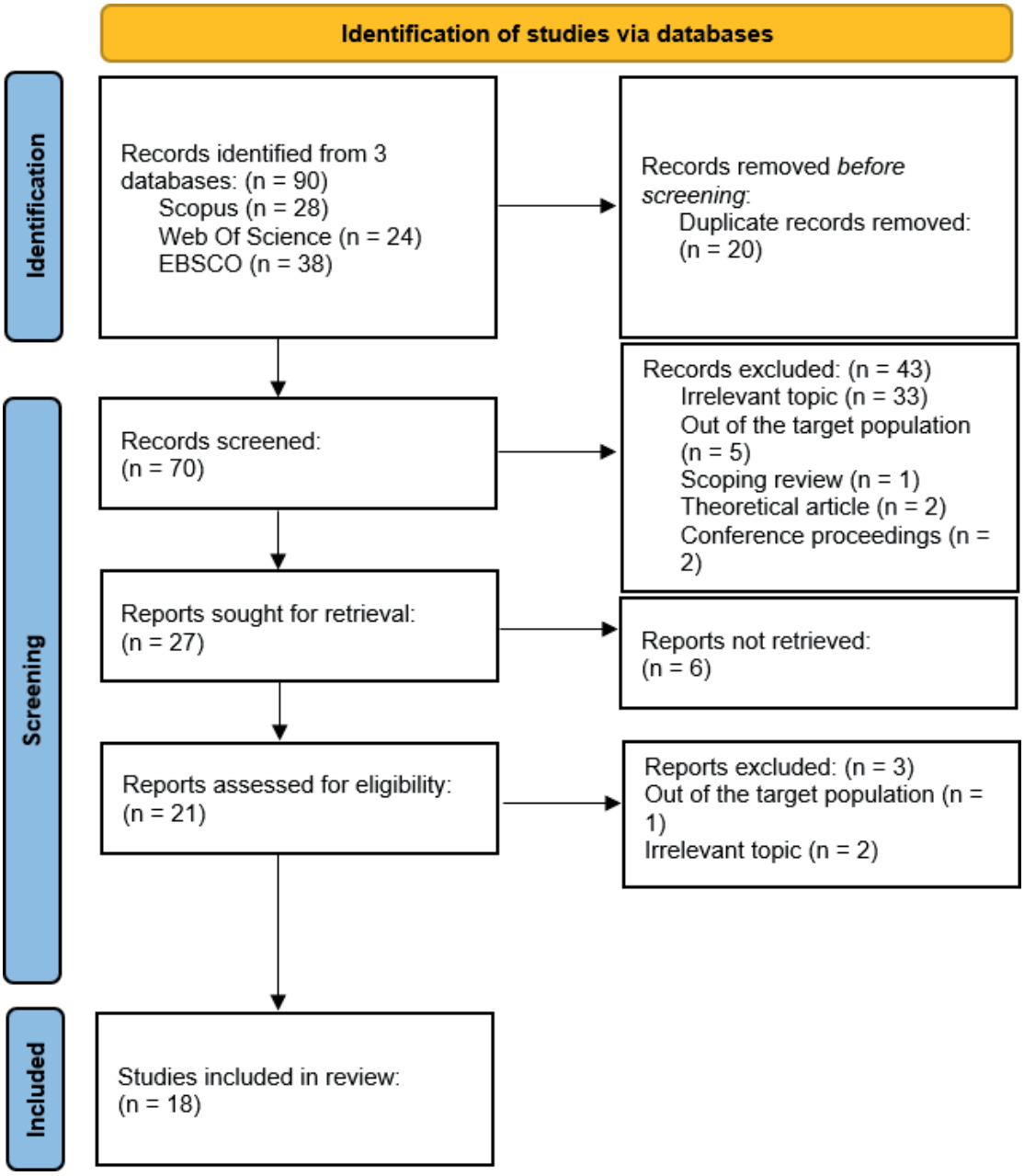

Figure 1. PRISMA flow chart of the selection process.

2.2. Population selection

The sample for the current review comprises students in formal education contexts (Table 1), aiming to evaluate the effectiveness of Minecraft-based educational interventions across a broad range of ages and educational settings.

To extract data from the papers, they were coded according to the following categories: (1) author(s) and year of publication, (2) title of the research, (3) place where the research was carried out, (4) target population, (5) topic of the research, (6) methodology used, and (7) research results.

To establish the methodological quality of this study, reliability was determined based on the survey and selection of Cohen's Kappa statistical index (for agreement) for two evaluators, according to which 0.81–1.00 represents an almost perfect agreement (Landis & Koch, 1977). For the extraction and selection of the data, a value of K = 0.89 was obtained.

Table 1. Search strategy.

Database	Research string	Population
Web Of Science, EBSCOhost Research Databases, SCOPUS	("game-based learning" OR "GBL") AND ("Minecraft") AND ("school")	K-12, school settings

3. Results and discussion

The relatively small number of papers (18) meeting our inclusion criteria for the 2019-2024 period warrants discussion. This limited sample size may reflect several factors: while Minecraft is widely used in educational contexts, much of this implementation may be happening at a practical level without formal research documentation. Additionally, the COVID-19 pandemic (2020-2022) likely impacted the ability to conduct and publish classroom-based research during this period. Despite the small sample size, these studies represent diverse geographical locations, educational contexts, and subject areas, providing valuable insights into Minecraft's educational applications while highlighting the need for more extensive research in this field.

Methodologically, the studies employ a diverse range of approaches. Qualitative methods predominate, allowing for in-depth exploration of teachers' and students' experiences and perspectives. Mixed methods approaches are also common, combining qualitative insights with quantitative data to provide a more comprehensive understanding of Minecraft's educational impact. Several researchers adopt a design case study approach, focusing on the development and implementation of Minecraft-based educational environments and games.

While qualitative and mixed-methods approaches dominate, there is a notable variation in the rigor and scale of these studies. For instance, Slattery et al. (2024) conducted a large-scale mixed-methods study with 885 students across 32 classes, providing a robust dataset for analysis. In contrast, studies like Nkadimeng & Ankiewicz (2022) focused on a smaller sample of 20 students, allowing for more in-depth qualitative analysis but limiting generalizability.

The design-based research approach, exemplified by studies such as Jensen & Hanghøj (2020) and Kane et al. (2019), offers valuable insights into the process of developing and implementing Minecraft-based educational interventions. These studies appear helpful in evaluating outcomes, while also shedding light on the design principles and challenges encountered during the development process.

Table 2. Results.

Authors (year)	Title	Nation(s)	Target (sample number)	Topic	Minecraft's role	Methods	Results
Chang et al., (2024)	The Metaverse in Green Building Concept Learning, Creative Design Performance, and Learning Engagement	Taiwan	High school students (n=61)	Teaching sustainability	Used by researchers during a one-time 6-session (300-minute total) technology course intervention	Quantitative methods	Findings on the benefits of a VR-based Minecraft educational activity
Ivanov & Yordanov, (2024)	Application of Minecraft: Education in Mathematics and CMIT Classes, Examples and Practices	Bulgaria	Middle school students (n=n.a.)	Maths; teaching programming	Digital environment for game-based educational activities	Design case study	Development of a series of Minecraft-based educational activities
Slattery et al., (2024)	Effectiveness of a Minecraft Education intervention for improving spatial thinking in primary school children: A mixed methods two-level cluster randomised trial	Ireland	Primary school students (n=885)	Geography, spatial planning and spatial thinking	Six weekly teacher-facilitated Minecraft Education sessions with guided spatial thinking challenges over 6-8 weeks	Mixed methods	Improvements in spatial thinking
Sulaiman et al., (2024)	Empowering the Next Generation: Using Minecraft Education to Teach Solar Photovoltaic Concepts in Secondary School	Malaysia	High school students (n=40)	Science education	Used by researchers as an 8-week intervention during co-curricular activities to teach solar photovoltaic concepts through virtual experimentation	Mixed methods	Findings on the effectiveness of Minecraft as an educational tool to foster accessibility and engagement in science education
Slattery et al., (2023a)	Teachers' experiences of using Minecraft Education in primary school: An Irish perspective	Ireland	Primary school teachers (n=11)	Teachers' perspective	Used by teachers during a national initiative combining guided TV episode challenges and a sustainability-focused class project	Qualitative methods	Identification strengths and weaknesses in skill development
Slattery et al., (2023b)	Primary School Students' Experiences using Minecraft Education during a National Project-Based Initiative: An Irish Study	Ireland	Primary and middle school students (n=173)	Students' perspective	Used in a national project combining educational episodes and a sustainability-focused competition	Mixed methods	Identification of benefits in using Minecraft as an educational tool
Nkadimeng & Ankiewicz, (2022)	The Affordances of Minecraft Education as a Game-Based Learning Tool for Atomic Structure in Junior High School Science Education	South Africa	Middle school students (n=20)	Science education	Used in five 1-hour lessons to teach atomic structure through hands-on exploration of virtual atomic models and crafting stations	Qualitative methods	Findings on the affordances of Minecraft for teaching abstract concepts

(Continued)

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Table 2. (Continued).

Authors (year)	Title	Nation(s)	Target (sample number)	Topic	Minecraft's role	Methods	Results
Voštinár & Dobrota, (2022)	Minecraft as a Tool for Teaching Online Programming	Slovakia	Middle school students (n=19)	Teaching programming	Digital environment for coding tasks	Quantitative methods	Achieved high student interest and motivation in programming
Balnaves, (2021)	That cute creeper just blew up my house: Lessons in resilience in Minecraft games	Australia	Middle school students (n=24)	Building resilience	Game environment to foster collaborative strategies and resilience in difficult situations	Qualitative methods	Development of resilience strategies and informal gaming literacies by students
de Sena et al., (2021)	Challenges in the teaching of Cartography during the COVID-19 pandemic: use of Minecraft in the remote classroom setting	Brasil	Middle school students (n=178)	Geography, spatial planning and spatial thinking	The geography teacher implemented a 4-class sequence using Minecraft for cartography learning during remote teaching in late 2020	Qualitative methods	Minecraft-based student projects on cartography
Fogel et al., (2021)	Failures in Game-Based Learning Experiences Sometimes Win	Portugal	School students (n.a.) (n=142)	Game design	Game environment for a series of educational activities on nutrition literacy	Qualitative methods	Assessment of challenges and adversities in game-based educational design
MacLeod et al., (2021)	CumbraeCraft: A Virtual Environment for Teaching Cultural Heritage to Primary School children	Scotland	Lessons intended for primary school students	History and cultural heritage	Development of a custom Minecraft Education world consisting of eight heritage-focused lessons designed for teachers to use in primary classrooms	Design case study	Development of a Minecraft-based educational environment
Hewett et al., (2020)	The Acquisition of 21st-Century Skills Through Video Games: Minecraft Design Process Models and Their Web of Class Roles	Texas, USA	High school students (n=13, but 95 students collaborated with the participants on the six Minecraft projects)	Exploring gamers' behaviors	Students built collaborative themed virtual worlds in Minecraft over 6 weeks during Animation and Video Game Design courses	Qualitative methods	Generation of educational models

(Continued)

Table 2. (Continued).

Authors (year)	Title	Nation(s)	Target (sample number)	Topic	Minecraft's role	Methods	Results
Jensen & Hanghøj, (2020)	What's the math in Minecraft: a DesignBased Study of Students' Perspectives and Mathematical Experiences Across game and School Domains	Denmark	Primary school students (n=12)	Maths and geometry	A week-long teaching unit (15 lessons) used Minecraft to teach coordinate systems to fifth-graders through inquiry-based tasks	Qualitative methods	Design principles for the use of Minecraft in mathematics education
Čujdíková, (2019)	Create Minecraft Fame, Save the World	Italy	High school (n=n.a.)	Game design	Used as a game development tool	Qualitative methods	Analysis of the learning outcomes of a Minecraft-based game design course
Kane et al., (2019)	Escape from the Python's Den: An Educational Game for Teaching Programming to Younger Students	Alabama, USA	Educational game intended for PK-8 grades (kindergarten, primary school and middle school students) (n=n.a.)	Teaching programming	Used as a game environment for teaching Python programming	Design case study	Development of a Minecraft-based educational game to teach the basics of Python programming
Näykki et al., (2019)	Affective Learning in Digital Education-Case Studies of Social Networking Systems, Games for Learning, and Digital Fabrication	Finland	Primary school students (n=16)	Affective learning	Implemented in an 8-week after-school club with weekly 90-minute sessions and continuous access between meetings, following a structured educational program	Design case study	Design of a Minecraft-based educational game to foster knowledge and skill acquisition
Opmeer et al., (2019)	Using Computer Games to Mitigate Disaffected Emotions in the Geography Classroom. Lessons Learned from Small-Scale Research on Teaching Sustainable Spatial Planning with Minecraft	Netherlands	Secondary education (middle school and high school students) (n=101)	Geography, spatial planning and spatial thinking	Used over 8 weeks in geography classes for students to create and iterate sustainable spatial designs of artificial islands	Quantitative methods	Analysis of students' emotional engagement when using Minecraft for spatial planning

This approach is particularly valuable for educators and researchers looking to create their own Minecraft-based learning environments.

3.1. Demographics and age groups

The geographical distribution of these studies spans multiple continents, reflecting the global interest in Minecraft's educational potential. European nations are well-represented, with studies conducted in Ireland, Scotland, Denmark, and the Netherlands. The research also extends to North America (USA), South America (Brazil), Asia (Taiwan and Malaysia), and Africa (South Africa), indicating a widespread adoption of Minecraft as an educational tool across different cultural and educational contexts.

The target populations in these studies encompass a wide range of age groups within the K-12 education system. Primary school students and teachers feature prominently, with several studies focusing on this age group (Slattery et al., 2023b; MacLeod et al., 2021; Jensen & Hanghøj, 2020). Secondary education is also well-represented, with studies targeting middle school and high school students (Chang et al., 2024; Opmeer et al., 2019; Hewett et al., 2020). Notably, one study (Kane et al., 2019) even explores the use of Minecraft with kindergarten students, demonstrating the game's versatility across different developmental stages.

Our analysis reveals distinct patterns in Minecraft's educational effectiveness across different student groups. In the analyzed papers, primary school students, ages 5-11, show strong engagement and learning outcomes in structured, teacher-guided activities, as demonstrated by Slattery et al. (2024) and MacLeod et al. (2021). These younger learners benefit from clear objectives and consistent guidance, with teachers helping direct their exploration of the platform. Middle school students, ages 11-14, demonstrate optimal results with hybrid approaches combining structure and creative freedom, as evidenced in de Sena et al.'s (2021) work. This age group shows particular success when allowed to experiment within defined parameters, balancing creative expression with learning objectives. High school students, ages 14-18, benefit from project-based applications focusing on complex problem-solving, as shown in the works of Chang et al. (2024) and Sulaiman et al. (2024). These older students demonstrate capacity for sophisticated applications of the platform, particularly in domains requiring abstract thinking and multiple-step problem solving. Additionally, Balnaves (2021) explored the building of resilience skills in an after-school club for adolescents aged 12–14, underscoring how middle school students leverage Minecraft's collaborative potential to foster both emotional and cognitive growth through group challenges and quests. This aligns with the earlier observation that middle school learners thrive on blended instructional strategies combining teacher-driven organization with significant creative expression. Similarly, in Ivanov and Yordanov' study (2024), students around early adolescence displayed heightened motivation when engaged with an open-world environment that was systematically linked to the mathematics and CMIT (Computer Modeling and Information Technologies) curricula.

3.2. Subject areas

The subject areas and topics addressed in these studies are diverse, showcasing Minecraft's adaptability as an educational platform. Several studies focus on geography, spatial planning, and spatial thinking (de Sena et al., 2021; Slattery et al., 2024; Opmeer et al., 2019), highlighting the game's inherent strengths in visualizing and manipulating 3D spaces. Mathematics and geometry are also promi-

nent themes (Jensen & Hanghøj, 2020), leveraging Minecraft's block-based environment for teaching mathematical concepts.

Science education emerges as another key area of focus, with topics ranging from atomic structure (Nkadimeng & Ankiewicz, 2022) to solar photovoltaic concepts (Sulaiman et al., 2024). This breadth demonstrates Minecraft's potential for teaching both abstract and concrete scientific principles. Additionally, the game has been applied to teaching sustainability and environmental concepts (Chang et al., 2024), aligning with the growing global emphasis on environmental education.

Our review reveals distinct patterns in Minecraft's effectiveness across different subjects. In STEM fields, mathematics and geometry applications showed particularly high effectiveness for spatial reasoning and geometric concept visualization in the study by Jensen & Hanghøj (2020). In Nkadimeng & Ankiewicz's (2022) work on atomic structure teaching, a science education application of Minecraft obtained strong results in abstract concept visualization and experimental design. Technology education showed excellent outcomes in introducing programming concepts in the study authored by Kane et al. (2019). In humanities applications, history and cultural heritage education benefitted from Minecraft's ability to facilitate historical reconstruction and cultural exploration in MacLeod et al.'s (2021) work. Geography education showed strong results in spatial planning and environmental education applications in the study carried out by Opmeer et al. (2019). Cross-disciplinary analysis suggests that while STEM applications generally show more immediate measurable outcomes, humanities applications excel in fostering engagement and creative expression.

Beyond traditional subject areas, several studies explore Minecraft's potential in developing 21st-century skills (Trilling & Fadel, 2009). Hewett et al. (2020), for instance, investigate the acquisition of these skills through video game design processes. The realm of programming education is addressed by Kane et al. (2019), who developed a Minecraft-based game to introduce Python basics to young learners. Cultural and historical education also finds representation in this corpus, with MacLeod et al. (2021) creating a virtual environment for teaching cultural heritage to primary school children, showcasing Minecraft's potential for creating immersive historical reconstructions and cultural experiences.

One common thread across many of these studies is the focus on student engagement and motivation. Minecraft's immersive and interactive nature appears to be a key factor in capturing students' interest and promoting active participation in learning activities. For example, de Sena et al. (2021) reported significant student interest and focus on completing their Minecraft-based cartography projects, just like Sulaiman et al. (2024) noted increased engagement and motivation in learning about solar photovoltaic technology through Minecraft.

It is noteworthy, though, that engagement alone does not appear to necessarily translate to improved learning outcomes. While many studies report positive effects on student motivation, the evidence for cognitive gains is more mixed. Slattery et al. (2024), for instance, found no overall statistically significant improvements in spatial thinking for their entire intervention group, although subgroup analysis revealed benefits for younger students. Experiences like this one highlight the need for careful consideration of age-appropriate interventions and the importance of aligning game-based activities with specific learning objectives.

An interesting approach is proposed by Čujdíková's study (2019), which illustrates how high school students integrated sustainable development themes into a self-made, three-dimensional Minecraft game. In that study, pupils explicitly selected one of the United Nations 2030 goals for their in-game challenge narrative and then designed playful solutions reflecting those global issues. This game creation process encouraged them to address real-world problems through collaborative ideation, reinforc-

ing the potential of Minecraft-based interventions for both creative problem-solving and sustainability awareness.

Minecraft's role in supporting collaborative learning emerges as another recurring theme. Studies like Hewett et al. (2020) and Chang et al. (2024) emphasize how Minecraft facilitates teamwork, communication, and peer learning: the game's multiplayer capabilities allow for the creation of shared virtual spaces where students can work together on projects, solve problems collectively, and engage in peer-to-peer teaching. This aspect aligns well with constructivist learning theories and the emphasis on developing 21st-century skills such as collaboration and communication.

Interestingly, several studies highlight Minecraft's potential for fostering creativity and enabling students to express themselves in novel ways. MacLeod et al. (2021) and Chang et al. (2024) both note how Minecraft's open-ended nature allows students to explore and create freely, potentially unlocking creative abilities that might not be apparent in traditional classroom settings. This appears to be an interesting opportunity to engage students who might struggle with more conventional educational approaches.

An interesting case is the study by Fogel et al. (2021), involving the design a Minecraft-based intervention for nutrition literacy, which illustrates that the platform's sandbox environment can be adapted to convey health concepts, requiring students to complete quests and tasks focused on balanced eating behaviours. Their pilot program, in the context of a formal secondary school setting, revealed that students enhanced their conceptual understanding of nutritional science while drawing on digital problem-solving and collaboration skills. This is coherent with prior indications that the open structure of Minecraft fosters synergy between disciplinary knowledge (including health education) and 21st-century competencies such as adaptability and teamwork.

Meanwhile, Ivanov and Yordanov (2024) discuss the specifics of applying Minecraft in mathematics and CMIT classes, where the core aim was to promote algorithmic thinking and computational problem-solving through in-game building challenges. Their examples and practices mirror earlier references in the corpus, arguing that mathematics-based tasks (like coordinate geometry or measurement) are neatly illustrated by Minecraft's block-grid environment, further corroborating Jensen and Hanghøj's (2020) emphasis on geometry and spatial awareness. Additionally, studies by Voštinár and Dobrota (2022) underscore that Minecraft's environment can be integrated into programming lessons in an online setting, thereby translating abstract coding concepts into manipulations of a three-dimensional world. These experiences point to common ground on how Minecraft can be adapted to support computational thinking in tandem with standard disciplinary content.

3.3. Teacher competencies and support structures for successful implementation

Teacher competencies are another important factor in successful implementation, with three essential areas of expertise identified across the studies. First, technical proficiency with Minecraft and related tools forms the foundation of successful implementation. Second, game-based learning pedagogical skills enable teachers to effectively integrate the platform into their teaching practice. Third, subject-specific integration strategies allow for meaningful alignment with curriculum objectives. Studies reporting comprehensive teacher training, such as Slattery et al. (2023a), consistently show better results than those with minimal preparation.

The role of teachers in implementing Minecraft-based interventions emerges as a crucial factor across several studies. Slattery et al. (2023a) emphasize the importance of professional development for teachers to effectively integrate Minecraft into their teaching practices: teachers' comfort level with the

technology, their ability to design engaging and relevant activities, and their skill in facilitating game-based learning all contribute to the success of Minecraft interventions. Comprehensive teacher training and support when implementing game-based learning initiatives would likely mitigate the risk of inefficient implementations.

Fogel et al. (2021) stressed that teacher training was decisive in dealing with unexpected in-game failures, ensuring that mistakes became productive learning moments rather than sources of frustration. This resonates with the aforementioned consensus that educators must cultivate at least three areas of expertise – technical skills in Minecraft, pedagogical understanding of game-based frameworks, and the capacity to align game activities with curriculum requirements. Additionally, Balnaves (2021) found that teachers who underwent specific training to incorporate reflection practices (e.g., structured debriefing sessions after crucial game events) were more effective in guiding learners to articulate resilience strategies. By serving as "metacognitive coaches", teachers helped students generalise their in-game resilience approaches to broader academic challenges.

Like Slattery et al. (2023a) had observed, Ivanov and Yordanov (2024) concluded that teachers who shared lesson-design responsibilities and engaged in collaborative planning were better able to integrate Minecraft tasks cohesively. Their case demonstrates how shifting from a solo teacher model to a collaborative teaching team can amplify the game's educational impact, as more educators share technical know-how and better embed game experiences into official lesson sequences. Similarly, in programming classes described by Voštinár and Dobrota (2022), continuous teacher coaching and online follow-up sessions significantly helped novices facing the steepness of the learning.

3.4. Barriers and potential solutions

Various challenges emerged from these studies. Technical issues emerge as a common concern across several studies: Slattery et al. (2023b), Nkadimeng & Ankiewicz (2022) and Ivanov & Yordanov (2024) all report problems related to device availability, internet connectivity, and software compatibility. These technical hurdles can disrupt learning activities and potentially exacerbate existing inequalities in access to digital resources. Proposed remedies include robust teacher training in troubleshooting, explicit user-friendly installation guides, and preliminary "tech-check" sessions prior to curricular usage. Additionally, the asynchronous or remote contexts, as described by Balnaves (2021) and Voštinár and Dobrota (2022), create further complexity – mainly regarding internet connectivity, server hosting issues, and collaboration difficulties. Potential solutions revolve around ensuring that teachers and students have advanced notice of required technical capabilities, plus the necessary infrastructural support from schools or educational authorities. As educators consider implementing Minecraft-based interventions, careful attention must be paid to ensuring adequate technical infrastructure and support to ensure effective results.

There is a great impact of the culture of the country in which the experiments took place, in particular with respect to the involved teachers, as well as the availability of resources and training in formal education. This is evident in the geographical distribution of the studies, which shows uneven implementation across different regions. While European nations (Ireland, Scotland, Denmark, Netherlands), North America (USA), South America (Brazil), Asia (Taiwan and Malaysia), and Africa (South Africa) are represented in the research, there are notable gaps in coverage. The varying levels of technological infrastructure and teacher support across these countries appear to influence implementation success. For instance, studies from well-resourced educational systems like Ireland (Slattery et al.,

2023a) were able to implement comprehensive teacher training programs, while studies from other regions faced more fundamental challenges with device availability and internet connectivity (Nkadimeng & Ankiewicz, 2022). These disparities in resources and support structures highlight the need for further research into the possible sociomaterial barriers hindering Minecraft's diffusion in formal education settings across different cultural and economic contexts.

Another challenge identified in some studies is the potential for distraction or off-task behaviour. Nkadimeng & Ankiewicz (2022) and Balnaves (2021) noted that some students got distracted by exploring unrelated game features, potentially detracting from the intended learning objectives. Careful scaffolding and guidance when using Minecraft may be helpful in addressing this issue. Striking a balance between allowing for open-ended exploration and ensuring that students remain focused on the learning goals at hand seems to be a fundamental objective to strive for: while some off-task exploration may foster creativity or produce unexpected positive outcomes, excessive deviation can hinder completion of mandated objectives. Fogel et al. (2021) and Balnaves (2021) both suggest harnessing reflection cycles as a self-regulatory mechanism, where students themselves discuss project requirements and define "productive vs. unproductive" forms of exploration. This approach positions students as active co-managers of their learning environment, pairing teacher-led scaffolding with student autonomy in shaping in-game norms.

One barrier emphasised by Fogel et al. (2021) is that educators sometimes underreport negative or null results, leading to publication bias in the game-based learning literature. Specifically, their analysis reveals that teacher or researcher reticence about "failures" can compromise iterative improvements in design. They propose cultivating a community of practice where educators can openly exchange not only success stories but also difficulties and pitfalls, thus collectively advancing the field.

The results of our review show that, while Minecraft offers significant potential as an educational tool, its effectiveness depends heavily on the context and manner of its implementation. The studies reviewed here suggest that Minecraft can be a powerful platform for engaging students, promoting collaboration, and fostering creativity, but the mixed results in terms of cognitive gains and the challenges associated with technical implementation indicate that there are still many possibilities for refinement and improvement.

Moreover, the diversity of subject areas and topics addressed in these studies highlights Minecraft's versatility as an educational platform. From geography and mathematics to science and cultural heritage, Minecraft's block-based environment seems adaptable to a wide range of educational contexts. This flexibility is both a strength and a challenge – while it allows for creative applications across the curriculum, it also requires careful instructional design to ensure that the game-based activities align closely with specific learning objectives.

4. Conclusions

This systematic review of 18 peer-reviewed studies published between 2019 and 2024 reveals both the potential and challenges of integrating Minecraft into formal educational settings. The findings demonstrate that Minecraft-based interventions can enhance student engagement, spatial thinking abilities, and creativity across various subject areas from science to cultural heritage. The game's versatility allows it to support different pedagogical approaches, from structured activities for younger learners to complex project-based learning for older students. However, successful implementation requires careful consideration of technical infrastructure, teacher training, and curriculum alignment.

The studies indicate that while student motivation generally increases with Minecraft-based learning, cognitive gains vary depending on factors such as age group, subject matter, and implementation strategy. Collaborative learning and creative expression emerge as particular strengths of the platform, though challenges persist around managing technical issues, preventing distraction, and ensuring consistent learning outcomes.

The choice to include students in formal education contexts was supported by the fact that game-based learning has been proven to be effective and engaging as early as kindergarten (Plass et al., 2015). Minecraft has been shown to be an incredibly engaging, skill-developing, and creativity-stimulating tool outside of the educational context (Lane & Yi, 2017). Considering this and taking into account the efforts of its creators to bring it into classrooms (Kuhn, 2018), it was decided to focus on its applications in formal, rather than informal, education.

The reviewed studies highlight the need for age-appropriate methodological frameworks to effectively integrate Minecraft into school curricula. For primary school students (ages 5-11), structured activities with clear objectives and significant teacher guidance appear most effective, as demonstrated by Slattery et al. (2024) and MacLeod et al. (2021). These younger learners benefit from scaffolded exploration and direct instruction in basic game mechanics before engaging in educational tasks. For middle school students (ages 11-14), a balanced approach combining structured activities with opportunities for creative expression seems optimal, as shown in de Sena et al.'s (2021) cartography projects. High school students (ages 14-18) demonstrate capacity for more complex, project-based learning approaches, as evidenced by Chang et al.'s (2024) work on sustainable architecture and Sulaiman et al.'s (2024) physics education implementation. Across all age groups, successful integration requires clear alignment with curriculum standards, detailed lesson plans, formative assessment strategies, and professional development for teachers. The studies suggest a gradual progression from teacher-directed to student-centered activities as learners become more proficient with both the platform and subject matter.

As research in this field progresses, more longitudinal studies to assess the long-term impact of Minecraft-based interventions on student learning and skill development would be welcome. These extended studies could provide valuable insights into how the skills and knowledge acquired through Minecraft-based learning transfer to other domains and persist over time. Additionally, future research could benefit from more rigorous experimental designs, including randomized controlled trials, to more definitively establish the causal effects of Minecraft-based learning on various educational outcomes. Such studies would help to isolate the specific impact of Minecraft interventions from other factors and provide stronger evidence for its effectiveness.

Furthermore, future research should explore how Minecraft can be most effectively integrated into existing curricula across different subject areas. This includes a larger adoption of standardized assessment tools to measure learning outcomes in Minecraft-based environments, which can facilitate comparisons across different studies and interventions. There is also a need for more research on how Minecraft can support inclusive education, including its potential benefits for students with special educational needs or from diverse cultural backgrounds.

As the field of game-based learning continues to evolve, researchers should also investigate how Minecraft can be combined with other emerging technologies, such as virtual and augmented reality, to create even more immersive and interactive learning experiences. Additionally, exploring the potential of Minecraft for developing critical 21st-century skills like digital literacy, computational thinking, and collaborative problem-solving could provide valuable insights for educators and policymakers.

Building on the insights gained from these studies will be crucial to developing best practices for leveraging this popular game in service of meaningful learning experiences. By addressing the challenges identified in current research and exploring new avenues for implementation and assessment, educators and researchers can work towards fully realizing the potential of Minecraft as a powerful tool for engaging, interactive, and effective learning across diverse educational contexts.

5. Authors' contributions

Author 1 contributed to the article by analysing the data, discussing the results and envisioning the research question and its theoretical framework.

Author 2 contributed to the article by writing the conclusions, analysing the data and reviewing the final text.

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Exploring gender dynamics in gamified physics learning – investigating gamification's impact on engagement and learning across genders

Esplorare le dinamiche di genere nell'apprendimento della fisica attraverso il gioco – indagare l'impatto della gamification sull'impegno e l'apprendimento tra i generi

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ABSTRACT This study examines the effects of gamification on student engagement, motivation, and learning outcomes in the Basketball Physics Challenge, a physics-based educational game. Twenty secondary school students (aged 15-18) participated in a crossover study, experiencing both gamified and standard versions of the game. The findings revealed no significant overall gender differences in motivation or performance. However, female learners showed a decrease in motivation after transitioning to the gamified condition, while male learners exhibited a slight increase. Performance metrics indicated males initially scored higher in the gamified condition, while females demonstrated higher engagement, which declined over time. A multivariate ANOVA identified significant gender effects on performance. These results suggest gamification may enhance male learners' performance, while sustaining female engagement may require adaptive strategies. The study highlights the need for gender-specific approaches in gamified educational technologies and suggests further research with larger, more diverse samples to better understand the impact of gamification on learning outcomes.

KEYWORDS Gamification; Motivation; Gender Differences; Learning Outcomes; Physics Education.

SOMMARIO Questo studio esamina gli effetti della gamification sul coinvolgimento, la motivazione e i risultati dell'apprendimento degli studenti nella Basketball Physics Challenge, un gioco educativo basato sulla fisica. Venti studenti di scuola secondaria (di età compresa tra i 15 e i 18 anni) hanno partecipato a uno studio incrociato, sperimentando sia la versione gamificata che quella non gamificata del gioco. I risultati non hanno rivelato differenze significative tra i sessi per quanto riguarda la motivazione o le prestazioni. Tuttavia, le studentesse hanno mostrato un calo della motivazione dopo il passaggio alla condizione gamificata, mentre gli studenti maschi hanno mostrato un leggero aumento. Le metriche delle prestazioni hanno indicato che i maschi hanno inizialmente ottenuto punteggi più alti nella condizione gamificata, mentre le femmine hanno dimostrato un maggiore impegno, che è diminuito nel tempo. Un'ANOVA multivariata ha identificato effetti significativi del genere sulle prestazioni. Questi risultati suggeriscono che la gamification può migliorare le prestazioni degli studenti maschi, mentre per sostenere l'impegno delle donne possono essere necessarie strategie di adattamento. Lo studio evidenzia la necessità di approcci specifici per genere nelle tecnologie educative gamificate e suggerisce ulteriori ricerche con campioni più ampi e diversificati per comprendere meglio l'impatto della gamificazione sui risultati dell'apprendimento.

PAROLE CHIAVE Gamification; Motivazione; Differenze di Genere; Risultati di Apprendimento; Educazione alla Fisica.

1. Introduction

Gender dynamics play a significant role in shaping students' experiences in gamified physics learning environments. By examining how gamification influences engagement and learning outcomes across genders, educators can develop tailored approaches that address the diverse needs and preferences of all students. Given the considerable interest in boosting women's motivation and self-efficacy toward STEM subjects such as physics, it is essential to ensure that strategies like gamification are not inadvertently detrimental due to unforeseen gender differences in their effectiveness (Niepel et. al., 2019, Diekman et al., 2010; Boucher et al., 2017). This study reveals the potential of gamification not only to enhance engagement but also to address gender-specific responses, ultimately improving the overall learning experience for all students.

2. Theoretical framework

2.1. Introduction to gamification in education

Game-based learning (GBL) uses games explicitly as the medium for delivering educational content (Plass et al., 2015). Wu (2023) emphasises that Digital Game-Based Learning (DGBL) employs game mechanics to enhance student motivation and learning outcomes, underscoring the role of educators in effectively integrating these tools into classroom practices to align with pedagogical goals. Educational games, frequently employed in GBL contexts, furnish students with opportunities to explore, solve problems, make decisions, and tackle challenges within a structured and interactive framework (Flores, 2016). The impact of these games is twofold: they enhance academic achievement and boost learners' confidence and enthusiasm for learning. These benefits align with the broader educational goals of promoting personal and emotional growth in students (Wei et. al., 2024).

A different, related approach is represented by gamification, the use of game design elements in non-game contexts (Deterding et al., 2011). In the context of education, this involves the integration of specific game mechanics, such as points, badges, leaderboards, and challenges, into the learning process to foster motivation and engagement, without using a full-fledged game. Gamification in education has attracted considerable attention in recent years as a strategy to enhance learning outcomes and student engagement (Deterding et al., 2011). This approach rekindles students' interest in the learning process by making it more appealing and interactive (Malahito & Quimbo, 2020). Research has consistently shown that gamified learning positively influences student motivation, engagement, attitudes, and performance (Hazan et al., 2018). This approach enables students to connect academic tasks to their areas of interest, cultivating a positive disposition toward learning (Karabıyık, 2024). Research indicates that gamification design significantly contributes to academic participation and influences learners' engagement in such environments (Zaric et al., 2021). Gamified learning environments can have a positive impact on cognitive engagement, success, and student motivation (Özhan & Kocadere, 2019). Additionally, the adoption of gamified learning strategies has been linked to potential enhancements in students' willingness to engage in the educational process, learning outcomes, habits, and socialization skills (Kostolányová & Klubal, 2018).

2.2. Gender differences in learning and gamification

Gender differences in learning have been a subject of significant interest in educational research, with studies exploring various aspects such as gender differences in education, gender and motivation in

learning, the impact of gamification on male and female learners, and gender differences in educational performance. These investigations shed light on the nuanced ways in which gender influences learning outcomes and educational experiences. This is especially important in the context of the European Union's effort to reduce gender gaps in STEM education and careers (European Parliament, 2021).

The impact of gamification on male and female learners has been explored, revealing differences in how gamified learning environments influence motivation and engagement based on gender (Chung & Chang, 2017). While male learners may exhibit a higher preference and motivation for digital game-based learning, female learners might demonstrate higher cognitive abilities in certain aspects of the learning content (Chung & Chang, 2017). Efforts to reduce gender gaps in STEM teaching must account for the potential unintended consequences of teaching techniques that might be more effective for one gender than the other. Failing to address these disparities could inadvertently reinforce existing inequities (European Parliament, 2021).

Understanding gender-specific responses to gamification can help educators design more inclusive learning experiences that meet the diverse needs of all students, while also promoting gender equity in educational and career outcomes.

2.3. Gamification as a tool to bolster motivation

Gamification is increasingly recognized for its potential to transform traditional learning experiences by making them more interactive, enjoyable, and rewarding (Martí-Parreño et al., 2016). However, its impact on intrinsic and extrinsic motivation depends significantly on the design and implementation of game elements. While gamification can foster intrinsic motivation by creating engaging learning environments, it also leverages extrinsic motivators such as points, badges, and leaderboards to enhance engagement (Deci & Ryan, 1985; Khatoon, 2023).

While extrinsic motivators have the potential to enhance engagement initially, an over-reliance on these elements may result in a shift from meaningful learning to the accumulation of rewards. This phenomenon has been critiqued by Robertson (2010) as "pointsification". To counteract this, Hellberg and Moll (2023) argue that effective gamification should go beyond superficial rewards and incorporate game-thinking principles – such as narrative, interactivity, and problem-solving – to sustain intrinsic motivation.

Additionally, gamification can enhance learner autonomy and competence, key components of Deci and Ryan's (1985) Self-Determination Theory, by making abstract concepts more tangible and fostering experiential learning opportunities.

Gamification design is also relevant for gender differences in gamified activities' reception. Male learners often engage more with competitive elements, while female learners may prefer collaborative or narrative-driven tasks (Chung & Chang, 2017). To ensure inclusivity, gamification strategies should incorporate diverse approaches that cater to different motivational drivers. The thoughtful integration of both intrinsic and extrinsic elements has the potential to engender sustained engagement and equitable learning experiences, whilst simultaneously mitigating potential gender disparities in motivation and performance.

3. Present study

The primary aim of the Basketball Physics Challenge project was to assess how gamification elements influence student engagement, motivation, and learning outcomes in an educational game

designed to impart basic physics concepts. With the growing integration of digital educational technologies in classrooms, this game offers an innovative, hands-on approach to understanding theoretical concepts such as initial velocity, motion and trajectory, throwing angle, gravity, friction, and air resistance. Another key objective was to examine how varying sequences of gamified and non-gamified conditions impact learning outcomes and motivation over time.

3.1. Research objectives and hypotheses

Based on the project's main goal of exploring the impact of gamification on engagement, motivation, and learning performance in physics, we aimed to investigate the effects of gamification elements on female and male learners for their performance and motivation in a physics learning app. Given the small sample size, the analyses are framed as exploratory, and the results should be interpreted with caution due to limitations in statistical power. The following hypotheses were formulated and tested:

Hypothesis 1: Gender Differences in Motivation. It is expected that there will be significant differences in self-reported motivation between male and female learners prior to and after using the gamified physics learning app. This hypothesis will be tested by analyzing self-reported motivation scores before and after each session.
Hypothesis 2: Impact of Gamification on Learning Performance. This hypothesis posits that the use of gamification in the physics learning app will result in significant differences in learning performance (measured by time on task and scores) between male and female learners.

These hypotheses aim to provide deeper insights into the effects of gamification on engagement, motivation, and learning performance in physics-based educational games. While the results are exploratory, the study seeks to highlight the potential of gamification to sustain engagement and improve learning outcomes, focusing on understanding its effects on different learner demographics.

4. Method

4.1. Participants

The study involved 20 students from a secondary school in Liechtenstein, who were in the optional 10th grade, an additional school year following the regular curriculum. Participants ranged in age from 15 to 18 years ($M = 16.25$, $SD = 0.76$). The sample consisted of an equal distribution of 10 female and 10 male students. Sixty-five percent of the participants were native German speakers. The overall physics scores of the students were generally on the lower end, indicating that their performance was modest relative to expected proficiency levels for 10th-grade students. While specific national benchmarks were not available, the observed mean scores suggest that participants may have faced challenges in physics, which could influence their engagement and learning outcomes when using the gamified learning app.

4.2. Study design

The study employed a crossover design to examine the effects of gamification on performance and motivation in an educational game. Participants were divided into two groups to compare two game versions: one with gamification elements (the gamified condition) and one without (the standard condition). Each group experienced both versions in different sequences, allowing for individual differences to be controlled while reducing the number of required participants.

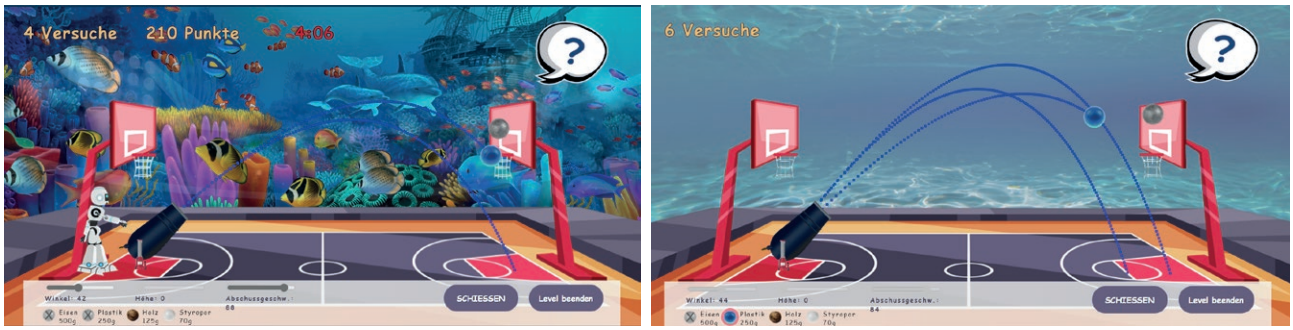

Figure 1. Screenshots of the Basketball Physics Challenge, with the gamified version on the left and the non-gamified version on the right, highlighting the differences between the two modes.

Participants were randomly assigned to one of two groups:

- **Group 1:** Played the gamified version in Session 1 (t1) and the standard version in Session 2 (t2).
- **Group 2:** Played the standard version in Session 1 (t1) and the gamified version in Session 2 (t2).

The purpose of this sequence was to investigate the effects of gamification across time while minimizing order effects. Session 1 served as the baseline measurement, and Session 2 allowed us to observe changes in performance and motivation when participants switched conditions.

Physics comprehension was measured through a quiz administered before and after each game version. Additionally, a motivation questionnaire was given before and after each session to assess changes in self-reported motivation.

Differences Between Gamified and Standard Versions. The Basketball Physics Challenge was offered in two versions: a gamified and a standard version, designed to explore gamification's impact on motivation and engagement. The gamified version featured colorful visuals, playful graphics, and an immersive robot avatar, contrasting with the plain design of the standard version. It also included engaging game mechanics, such as a timer to create urgency and a points system to reward task completion.

Storytelling and competitive elements further distinguished the gamified version, embedding physics problems within a narrative to enhance relatability. The standard version, by contrast, presented the same tasks without these features, using a straightforward and traditional format.

These gamified enhancements aimed to boost immersion, motivation, and accomplishment, illustrating gamification's potential to transform educational tools. In comparison, the standard version lacked these interactive and motivational elements, focusing solely on delivering the physics content.

4.3. Learning task and quiz structure

The learning task was designed to teach and apply basic physics concepts in an interactive environment. Participants completed a physics quiz before and after each gamified and standard version session, assessing their understanding of concepts such as initial velocity, motion, trajectory, throwing angle, gravity, friction, and air resistance. The game required players to adjust variables to throw a ball into a basket using a cannon, enabling them to test hypotheses about physical effects and learn through direct feedback.

4.4. Level structure and quiz integration

The game levels progressively introduced physics concepts, following a competency model aligned with international curricula, particularly the Swiss *Lehrplan 21* (NT.5.1.3.b). The thematic focus on forces and motion required students to explore the effects of forces, such as changes in a ball's trajectory. The domain was broken into atomic competencies – small units of knowledge or skills – to ensure a clear progression. Content began with basics like initial velocity and throwing angles, advancing to complex topics such as gravitational effects on different planets and wind resistance. This balance avoided excessive fragmentation while ensuring comprehensive coverage. Competency identification was guided by physics textbooks, *Lehrplan 21*, and research on misconceptions like parabolic motion and force relationships. A hierarchical competency tree visualised dependency, ensuring levels logically built upon each other to strengthen foundational knowledge. To evaluate understanding, participants completed a pre-test and post-tests for both game versions, allowing direct assessment of gamification's impact.

4.5. Motivation Questionnaire

A motivation questionnaire was administered at four key points (T1 pre, T1 post, T2 pre, T2 post) to assess changes across five motivational dimensions: intrinsic motivation, extrinsic motivation, well-being, emotional influence, and emotional factors.

Internal consistency was evaluated using Cronbach's alpha, revealing variability across dimensions and time points. Specifically, MOT1 exhibited low internal consistency at T1 pre ($\alpha = 0.27$) but demonstrated a substantial improvement at T1 post ($\alpha = 0.84$). In contrast, MOT2 displayed moderate internal consistency at T2 pre ($\alpha = 0.63$), with a slight increase at T2 post ($\alpha = 0.69$).Test-retest reliability, assessed through correlations between pre- and post-scores, indicated moderate stability for MOT1 ($r = 0.59$) and MOT2 ($r = 0.61$). These results suggest that MOT1 exhibited greater temporal fluctuations, while MOT2 maintained more stable reliability over time.

The validity of the questionnaire was supported by its theoretical foundation in established motivational constructs (Deci & Ryan, 1985) and the alignment of dimensions with key aspects of motivation. For interpretive consistency, negatively worded items were reverse-coded, ensuring that higher scores consistently reflected greater levels of motivation, satisfaction, or well-being. Responses were recoded and categorized into the five main dimensions, with mean scores calculated to provide aggregated results.

5. Results

The results of the Basketball Physics Challenge study offer comprehensive insights into the impact of gamification on teaching physics concepts and its influence on learning performance and motivation among male and female learners. Initial analyses visualized the group distribution across different measurement time points to illustrate participant engagement and participation. Descriptive statistics, including mean values and standard deviations, were calculated for total scores at each measurement point to assess learning progress and the effectiveness of gamification elements.

5.1. Gender differences in motivation

For male participants, no significant differences in motivation scores were found between pre- and post-intervention in Session 1 ($M = 15.04$, $SD = 0.94$ vs. $M = 14.11$, $SD = 2.94$), $t(8) = 1.03$, $p = .333$.

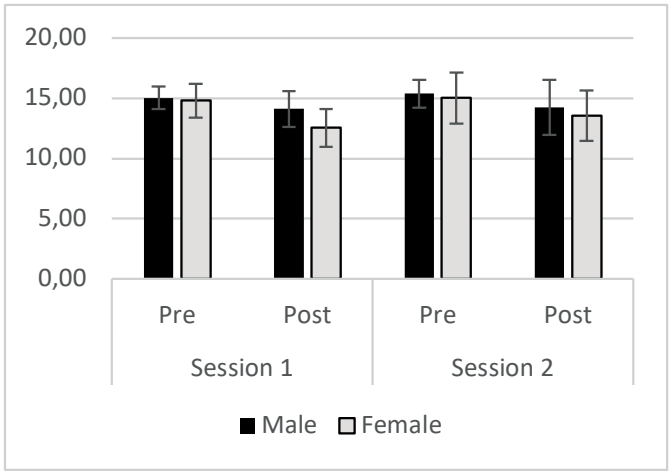

Figure 2. Self-Reported Motivation Scores for Males and Females Before and After Each Session. The chart illustrates the average motivation scores for male and female students before and after Session 1 and Session 2.

Similarly, in Session 2, the difference in motivation scores before (M = 15.38, SD = 1.15) and after (M = 14.23, SD = 2.29) using the app was not statistically significant, $t(8) = 1.58$, p = .153.

For female participants, significant decreases in motivation scores were observed in both sessions. In Session 1, motivation scores significantly declined from M = 14.80 (SD = 1.40) to M = 12.54 (SD = 3.38), $t(9) = 2.75$, p = .023, suggesting a notable reduction in motivation after using the app. In Session 2, this effect was even more pronounced, with a decline from M = 15.03 (SD = 2.11) to M = 13.54 (SD = 2.10), $t(9) = 3.51$, p = .007. The larger t-value in Session 2 indicates a stronger effect compared to Session 1, suggesting a cumulative or reinforcing negative impact of the intervention on female participants' motivation.

The findings indicate a differential impact of the learning app on male and female participants. While motivation levels for male participants remained stable across both sessions, female participants experienced a significant decline in motivation after using the learning app. This effect was more pronounced in the second session, potentially indicating that the gamification elements did not sustain engagement for female learners or that their initial expectations were not met over time. These results suggest the need for a more tailored approach in designing gamified learning interventions that better address gender-specific motivational dynamics.

Consistent with these results, we found homogenous results for motivation across gender and condition. The detailed mean values and standard deviations (SDs) for self-reported motivation scores before (pre) and after (post) using the learning app in both sessions are provided below (Table 1).

5.2. Gender differences in performance

Similarly, no gender differences were found in performance (time on task, scores) using the learning app in both sessions. A paired-samples t-test was conducted to examine potential differences in performance metrics, including time on task and scores, before and after using the learning app for both male and female participants.

Time on Task: For male participants, there was no significant difference in time on task between Session 1 (M = 609.11, SD = 147.30) and Session 2 (M = 611.56, SD = 148.10); $t(8) = -0.04$, p = .967. For

Table 1. Pre- and Post-Intervention Motivation Scores Across Different Conditions and Time Points. Values represent mean scores and their corresponding standard deviations (SD) for self-reported motivation before (pre) and after (post) the intervention across conditions (G_m: gamified condition, males; G_w: gamified condition, females; S_m: standard condition, males; S_w: standard condition, females) and sessions (t1: session 1, t2: session 2).

	G_m	G_w	S_m	S_w
t1 pre	14.88 (.86)	15.30 (1.16)	15.37 (1.21)	14.31 (1.59)
t2 pre	16.02 (.62)	13.84 (1.62)	15.06 (1.86)	16.21 (1.97)
t1 post	15.25 (1.37)	14.97 (1.37)	11.84 (4.27)	10.10 (3.00)
t2 post	15.29 (2.70)	12.27 (1.87)	13.70 (0.50)	14.81 (1.53)

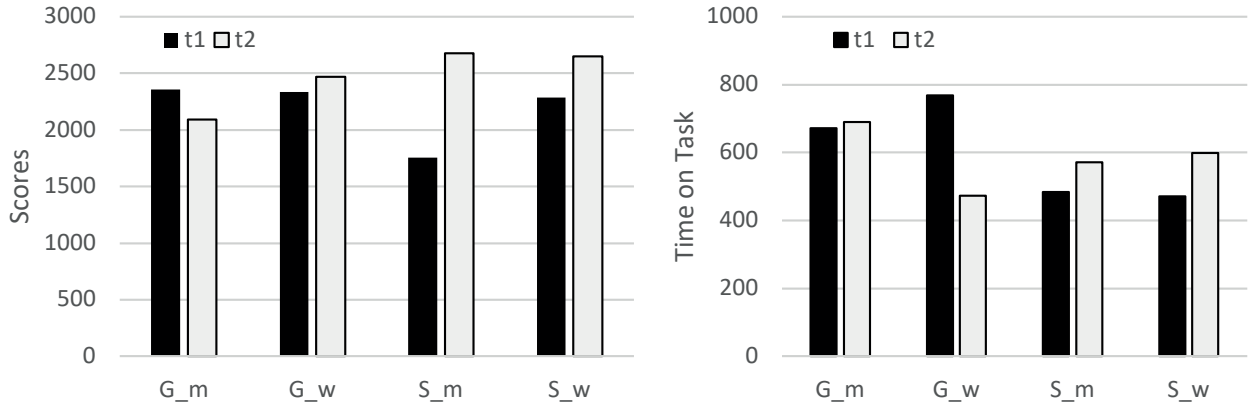

Figure 3. Comparison of Scores and Time on Task Between Sessions: **(a)** Performance scores for males (m) and females (w) in the gamification (G) and standard (S) conditions across sessions t1 and t2; **(b)** Time on task for males and females in both conditions.

female participants, a marginally significant decrease in time on task was observed between Session 1 (M = 620.30, SD = 228.03) and Session 2 (M = 536.00, SD = 135.74); $t(9) = 2.17$, p = .058.

Scores: For male participants, a significant increase in scores was found between Session 1 (M = 2154.44, SD = 404.11) and Session 2 (M = 2483.33, SD = 580.37); $t(8) = 7.99$, $p < .001$. For female participants, no significant difference in scores was found between Session 1 (M = 2310.00, SD = 296.06) and Session 2 (M = 2561.00, SD = 364.58); $t(9) = -1.51$, p = .167.

These results indicate that both male and female learners performed similarly in terms of time on task and scores, regardless of the gamification elements. While male participants exhibited a significant increase in scores from Session 1 to Session 2, female participants showed no significant improvement

5.3. Condition effects on performance

The analyses of condition effects on (gamification vs standard) revealed a distinct difference for males in scores in the standard condition. In session 1 (t1), males tended to achieve lower scores in the standard condition compared to session 2 (t2) (Figure 3a). A repeated measures ANOVA yielded a significant effect for the main factor condition ($F(1, 17) = 5.623$, p = .030, $h^2 = .06$). In turn, Figure 3b shows that female learners tended to spend more time on task in the gamification condition in session

1 and less time in the gamification condition in session 2, as opposed to the other groups (males and standard condition). The repeated measures ANOVA yielded a significant effect for the interaction Session * Condition ($F(1, 17) = 333.777$, $p < .001$, $h^2 = .50$). These findings suggest that gamification elements positively impacted males' scores, while females showed higher engagement in terms of time on task initially, but this engagement decreased over time.

5.4. Additional analyses

Given the within-subject design of the presented study, it is of interest to investigate the individual changes from session 1 to session 2. The results summarized in Figure 4a show that male participants experienced greater improvements in scores compared to females, particularly when starting with the standard condition followed by the gamification condition. While both GS_m and GS_w groups showed score increases, the increase was less pronounced for females in the SG_w group.

Figure 4b illustrates differences in time on task. Male participants in the SG_m group, who started with the gamified version, showed a clear increase in time on task, whereas females in the same sequence (SG_w) showed no changes. Participants in the GS_m and GS_w groups, who began with the standard condition, demonstrated a reduction in time on task during the second session.

A multivariate ANOVA yielded significant effects of gender on the score differences, highlighting that gender plays a crucial role in how learners respond to gamified versus standard conditions. The detailed results of the multivariate ANOVA are as follows:

For the Score Difference (SCORE_DIFF), the corrected model showed no significant overall effect ($F(3, 15) = 0.078$, $p = .971$, $h^2 = .01$). However, the constant term was significant ($F(1, 15) = 5.120$, $p = .039$, $h^2 = .25$), indicating that there were significant overall differences in scores. Regarding the Time on Task Difference (ToT_DIFF), the corrected model was highly significant ($F(3, 15) = 13.534$, $p < .001$, $h^2 = .73$), suggesting substantial differences in time on task across the conditions. The constant term was not significant ($F(1, 15) = 0.585$, $p = .456$, $h^2 = .04$), but significant effects were found for the main factor of gender ($F(1, 15) = 11.623$, $p = .004$, $h^2 = .44$) and condition ($F(1, 15) = 34.603$, $p < .001$,

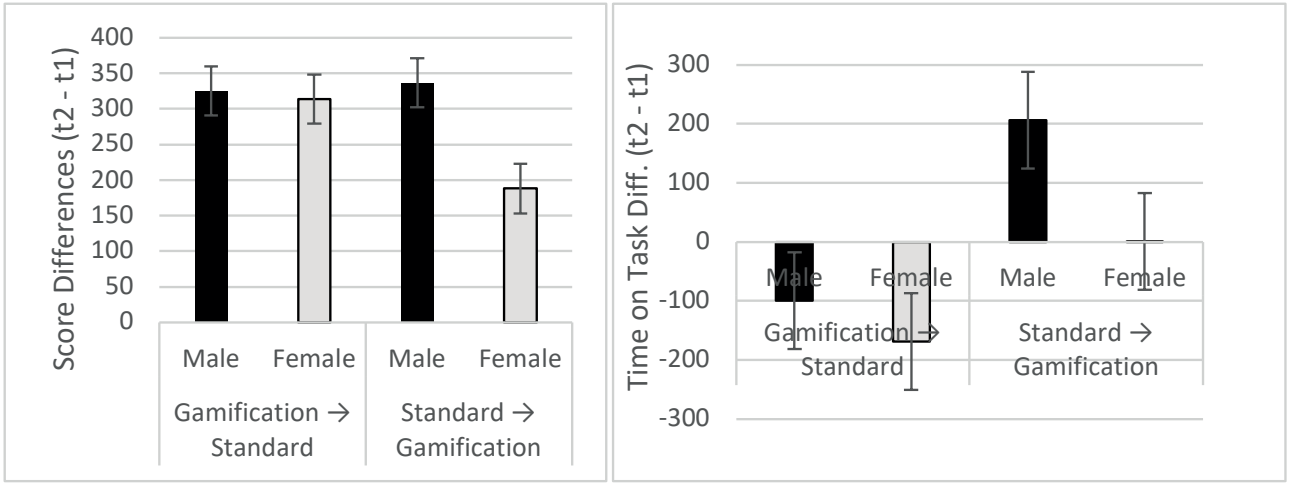

Figure 4. Differences in scores and time on task between sessions t1 and t2 for gamified (G) and standard (S) conditions across genders: **(a)** Score differences for males (m) and females (w); **(b)** Time on task differences for males and females.

Table 2. Pre- and Post-Intervention Scores Across Different Dimensions and Sessions. Values represent mean scores and their corresponding standard deviations (SD) for self-reported motivation before (pre) and after (post) the intervention across conditions (gamification-first, standard-first) and sessions.

		Session 1					Session 2				
		intrinsic	*extrinsic*	*wellbeing*	*emotional*	*emot.fact.*	*intrinsic*	*extrinsic*	*wellbeing*	*emotional*	*emot.fact.*
Pre	*G-S m*	3.08 (0.82)	3.11 (0.53)	2.89 (0.54)	3.17 (0.61)	2.63 (0.49	3.00 (0.35)	3.11 (0.34)	2.94 (0.34)	3.33 (0.52)	2.67 (0.34)
	G-S-f	2.95 (1.49)	3.40 (1.42)	2.80 (1.06)	3.30 (1.24)	2.85 (1.42)	3.35 (0.63)	3.18 (0.22)	2.93 (0.55)	3.40 (0.65)	3.35 (0.52)
	S-G-m	3.50 (1.49)	3.26 (1.42)	2.61 (1.06)	2.83 (1.24)	3.17 (1.42)	3.00 (0.00)	3.19 (0.42)	3.33 (0.58)	3.33 (0.58)	3.17 (0.29)
	S-G f	2.85 (1.49)	3.22 (1.42)	2.33 (1.06)	3.10 (1.24)	2.80 (1.42)	2.55 (0.91)	2.62 (0.78)	2.47 (0.57)	3.40 (0.55)	2.80 (0.21)
Post	*G-S m*	3.42 (0.82)	3.04 (0.57)	2.81 (0.49)	2.92 (0.55)	3.07 (0.41)	2.83 (1.17)	2.79 (0.90)	2.56 (0.56)	3.08 (0.58)	2.43 (0.64)
	G-S-f	3.30 (0.29)	2.80 (0.18)	2.93 (0.03)	3.30 (0.13)	2.64 (0.13)	2.80 (0.57)	3.00 (0.32)	2.73 (0.73)	3.40 (0.42)	2.88 (0.59)
	S-G-m	2.17 (0.28)	3.38 (0.05)	2.17 (0.06)	2.33 (0.10)	1.80 (0.03)	3.00 (0.00)	3.04 (0.07)	3.11 (0.19)	3.00 (0.00)	3.13 (0.23)
	S-G f	2.00 (0.60)	2.48 (0.62)	1.77 (0.51)	2.30 (0.54)	1.56 (0.65)	1.80 (0.84)	2.73 (0.19)	2.20 (0.52)	2.90 (0.74)	2.64 (0.46)

h^2 = .69). The interaction between gender and condition approached significance ($F(1, 15) = 2.852$, $p = .112$, $h^2 = .16$).

These results underscore the complex dynamics between gender, engagement, and performance in gamified educational settings. Males and females responded differently to the sequences of standard and gamified conditions, with significant implications for the design and implementation of educational technologies aimed at enhancing learning outcomes.

5.5. Subscales of motivation

The analysis of the five subscales of motivation – intrinsic, extrinsic, well-being, emotional, and emotional factors – yielded no distinct differences across gender and condition. Below are the detailed results for each subscale:

5.6. Effects of gamification sequence on motivation

The effects of the gamification sequence on self-reported motivation were analyzed across gender and intervention order, as illustrated in Figure 5. The overall motivation scores were calculated as the average of responses across four subscales: intrinsic motivation, extrinsic motivation, interest in physics, and satisfaction/well-being. Intrinsic motivation reflects enjoyment of and engagement with the task itself, while extrinsic motivation refers to external incentives, such as scores or rewards. Interest in physics captures enthusiasm for the subject matter, and satisfaction/well-being assesses emotional states, such as contentment or stress, during the sessions. As shown in Figure 5a, when investigating the self-reported motivation for the groups gamification first (G-S) and standard first (S-G) by gender in session 1, we found a distinct effect of the intervention order; males yielded an increase in self-reported motivation in the gamification condition (pre 14.88 (SD = 0.86); post 15.25 (SD = 1.37)), while females showed a decrease of motivation the gamification condition (pre 15.3 (SD = 1.16); post 14.97 (1.37)). In the standard condition, both genders yielded a decrease in motivation (males: pre 15.37 (SD = 1.21); post 11.84 (SD = 4.27); females: pre 14.31 (SD = 1.59); post 10.10 (SD = 3.00)). A repeated measures ANOVA yielded a significant main effect of gender ($F(1, 15) = 5.799$, $p = .015$, $h^2 = .45$) and

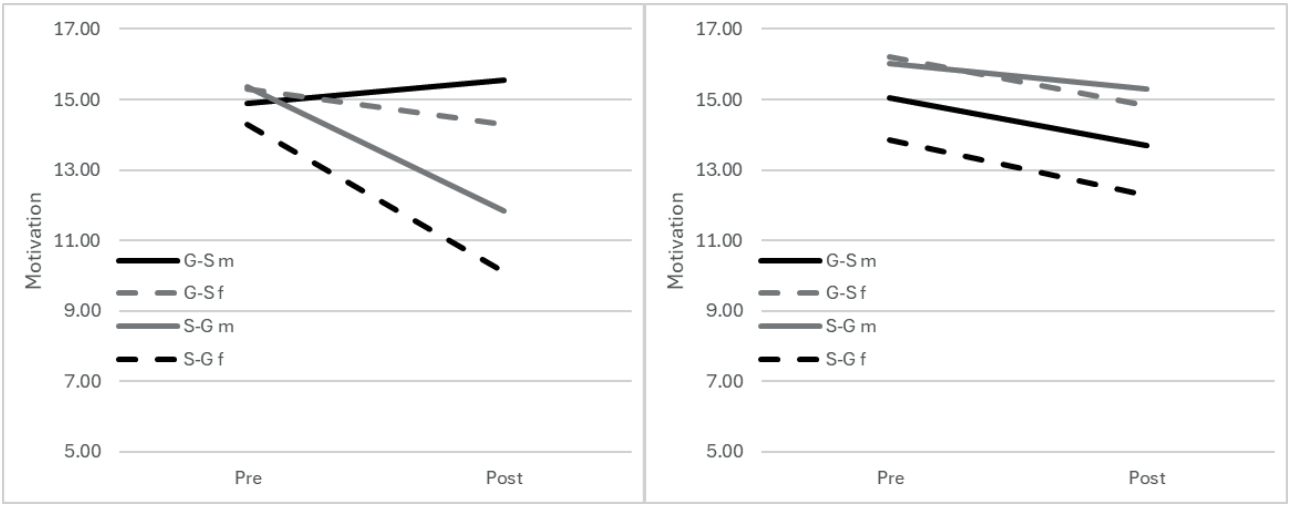

Figure 5. Changes in self-reported motivation before (Pre) and after (Post) the intervention for the gamification-first (G-S) and standard-first (S-G) sequences: **(a)** Motivation changes in Session 1 for males (m, solid lines) and females (f, dashed lines); **(b)** Motivation changes in Session 2 for males and females.

condition ($F(1, 15) = 16.430$, $p < .001$, $h^2 = .70$). The gender-group interaction was not statistically significant ($F(1, 15) = 1.477$, $p = .262$, $h^2 = .17$).

As shown in Figure 5b, when investigating the self-reported motivation for the groups gamification first (G-S) and standard first (S-G) by gender in session 2, we found a general drop in motivation. In condition G-S males reported a motivation of 16.02 (SD = 0.62) in the pretest and 15.29 (SD = 2.70) in the posttest, females a motivation of 13.84 (SD = 1.62) in the pretest and 12.27 (SD = 1.87) in the posttest. In condition S-G males reported a motivation of 15.06 (SD = 1.86) in the pretest and 13.70 (SD = 0.50) in the posttest, females a motivation of 16.21 (SD = 1.97) in the pretest and 14.81 (SD = 1.53) in the posttest. The repeated measures ANOVA yielded non-significant main effects of gender ($F(1, 15) = 1.048$, $p = .322$, $h^2 = .06$) and condition ($F(1, 15) = 0.685$, $p = .421$, $h^2 = .04$). The gender-group interaction was statistically significant ($F(1, 15) = 6.819$, $p = .020$, $h^2 = .31$).

These findings suggest a gendered pattern in response to the gamification sequence. Overall, the gamification condition affected males' motivation more positively than in females. Female participants' motivation decreased notably when exposed to the gamified condition first, indicating that gamification elements may not have effectively engaged or motivated them. In contrast, male participants responded more positively, particularly when the standard condition preceded the gamified intervention.

5.7. Individual changes in motivation

The individual change in motivation in pre-intervention motivation scores reflect the expectations to the app to some degree. As shown in Figure 6a, there were only marginal differences in the self-reported motivation. A multivariate ANOVA did not report significant differences. The individual change in motivation in post-intervention motivation scores reflect the effects of using the app. As shown in Figure 6b, the motivation after using the gamified app were clearly higher than after using the standard app. A multivariate ANOVA reported significant differences for the condition ($F(1, 15) = 7.618$, $p = .015$, $h^2 = .34$) but not for gender or for the gender by condition interaction.

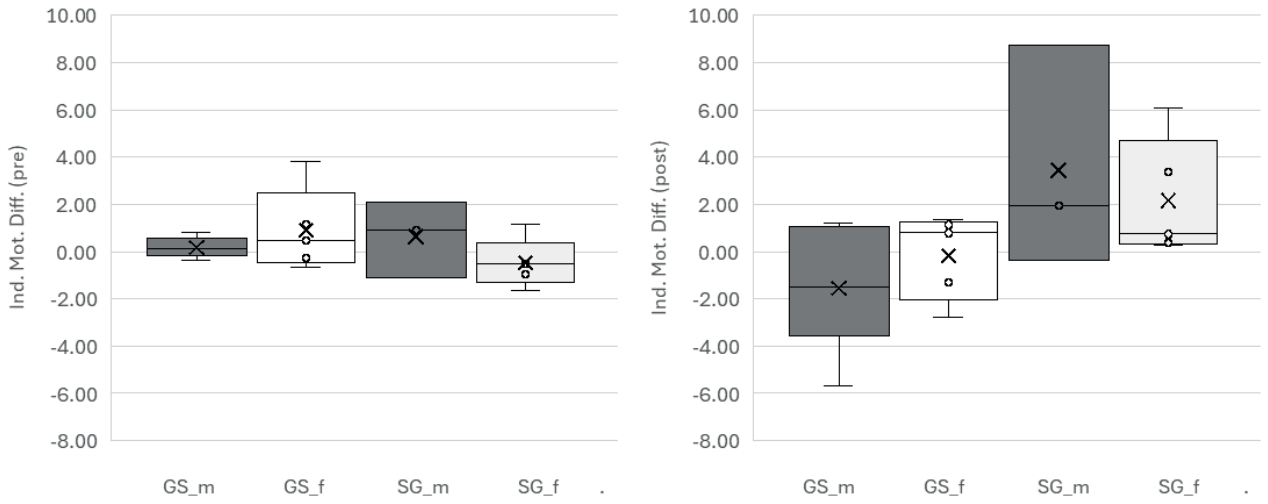

Figure 6. Differences in self-reported motivation for gamification-first (G-S) and standard-first (S-G) sequences: **(a)** Differences relative to pre-intervention scores for males (m) and females (w); **(b)** Differences relative to post-intervention scores across sessions for males and females.

5.8. Correlation analysis

To investigate the direct relationship between motivation and performance, correlation analyses were conducted separately for male and female participants. The results highlight significant relationships between motivation scores (pre and post), time on task, and scores in both sessions.

5.8.1. Male participants

Independent from condition, overall, we found moderate but non-significant positive correlations between the motivation prior and after using the app in Session 1 (r = .399, p = .288) and Session 2 (r = .337, p = .375). Also, there was a substantial but non-significant positive correlation between the motivation prior to using the apps in both sessions (r = .641, p = .063), however, there was no correlation between the motivation after using the apps across sessions (r = -.164, p = .673). This suggests a tendency that participants have a certain level of motivation independent of their expectations (confirming the results on the individual motivational change reported in section 5.6.). The weak correlation of motivation after sing the apps in Sessions 1 and 2 may imply that the condition (gamified, standard) influenced the individual motivational level.

The relationships between achieved scores as well as time on task and motivation was analysed separately by condition. In the standard condition the correlation between score and motivation prior to using the app was r = -.185 (p = .633) and r = .043 (p = .912) after using the app. The relationship between time on task and motivation was r = -.187 (p = .630) prior to using the app and r = .219 (p = .572) after using the app. Overall, there was little to no effect of the motivational level and performance (scores and time on task) in males. In the gamification condition the correlation between score and motivation prior to using the app was r = .465 (p = .207) and r = .155 (p = .690) after using the app. The relationship between time on task and motivation was r = -.514 (p = .157) prior to using the app and r = -.100 (p = .798) after using the app. Overall, there was little to no effect of the motivational

level and performance. This suggests that the gamification condition led to higher motivation in males and this, in turn, to higher scores. Notably, the motivation prior to using the app yielded a stronger relationship than after using the app. An explanation for this effect might be that not only the gamification experience but also the achievements (scores) could have influence post motivation. For time on task, we found an inverse relationship; the higher the motivation the shorter was the time on task. This suggests a possible tendency that highly motivated male participants worked faster. This pattern could reflect a trade-off where prolonged effort may not translate into improved performance, potentially due to factors such as inefficient strategies or cognitive overload. These correlations indicate a trend suggesting that for male participants, initial motivation levels may influence performance outcomes, and there is a notable trade-off in time on task across sessions. This implies that male learners who are initially highly motivated may spend less time on tasks yet achieve better performance, reflecting a more efficient use of their study time. This comprehensive interpretation incorporates the significant and non-significant findings from the other analyses as well, providing a nuanced understanding of the relationships between motivation and performance for male participants.

5.8.2. Female participants

Overall, we found string and significant positive correlations between the motivation prior and after using the app in Session 1 ($r = .693$, $p = .026$) and Session 2 ($r = .797$, $p = .006$). Also, there was a substantial and significant positive correlation between the motivation prior to using the apps in both sessions ($r = .677$, $p = .031$) and between the motivation after using the apps across sessions ($r = .709$, $p = .022$. These results suggest that female participants exhibited a stable motivational pattern across sessions, indicating that their motivation was less affected by external experimental conditions, such as gamification elements. This confirms the results on the individual motivational change reported in section 5.6., but also suggest that using the apps had less impact on post-session motivation in females compared to males.

The relationships between achieved scores as well as time on task and motivation was analysed separately by condition. In the standard condition the correlation between score and motivation prior to using the app was $r = .409$ ($p = .241$) and $r = .421$ ($p = .226$) after using the app. The relationship between time on task and motivation was $r = .202$ ($p = .576$) prior to using the app and $r = .510$ ($p = .132$) after using the app. As opposed to males, we found a strong positive effect of the motivational level on performance (scores and time on task) in the standard condition. In the gamification condition the correlation between score and motivation prior to using the app was $r = .131$ ($p = .718$) and $r = .006$ ($p = .986$) after using the app. The relationship between time on task and motivation was $r = .529$ ($p = .115$) prior to using the app and $r = .326$ ($p = .358$) after using the app.

Overall, the results for female participants showed a different pattern compared to males, with greater stability in motivation across sessions and a weaker impact of external conditions such as gamification. A moderate but non-significant trend suggested that more highly motivated female participants tended to achieve higher scores and spend more time on task, particularly in the standard condition. However, these trends should be interpreted with caution due to their lack of statistical significance. The consistency in motivational patterns over time may suggest a role for initial motivation in shaping engagement, but further research is needed to substantiate its influence on performance outcomes.

6. Discussion

The present study aimed to explore the impact of gamification on student engagement, motivation, and learning outcomes in the context of a physics-based educational game. By examining the effects of gamified and non-gamified (standard) conditions on male and female learners, the study sought to understand how these elements influence performance and motivation across different sessions.

6.1. Gender differences in motivation

Contrary to our initial hypothesis, the study found no significant overall gender differences in self-reported motivation scores before and after using the learning app across both sessions. However, significant within-group differences were observed, particularly among female participants. While males showed no significant changes in motivation across sessions, female learners exhibited a significant decline in motivation after using the learning app in both sessions. This effect was stronger in Session 2, suggesting a cumulative negative impact of the intervention on female learners' motivation. These findings indicate that while gamification did not differentially affect overall gender motivation levels, it had a stronger impact on motivational stability among female learners.

A closer examination of motivational trends revealed that females who transitioned from the standard to the gamified condition exhibited lower motivation scores, whereas male learners showed a more stable motivational pattern. These findings suggest that while gamification might initially engage female learners, this engagement does not sustain over time, possibly due to a perceived lack of relevance or appeal in the gamified elements. In contrast, males appeared to respond more consistently to gamification, suggesting potential differences in how gamification is perceived and valued by different genders. These findings align with prior research indicating that gender differences can influence learning motivation. Studies have shown that female students tend to demonstrate stronger self-regulation in online learning contexts, while male students may utilize more learning strategies and possess better technical skills (Puspitaningrum et al., 2021; Yu, 2021).

These differences underscore the multifaceted impact of gender on learning behaviours, emphasising the necessity for customised gamification strategies to address these variations. Conversely, when designed effectively, gamification has the potential to be universally beneficial for both genders (Ragusa et al., 2024). For instance, research has demonstrated that inclusive gamified approaches have the capacity to bridge gender gaps by integrating diverse challenges and rewards that appeal to a range of motivational factors. Such strategies emphasise equitable engagement, ensuring that both male and female learners remain motivated over time (Ragusa et al., 2024).

The observed differences highlight the crucial relationship between motivation and engagement. When motivation decreases, engagement in learning activities tends to decline, as evidenced by the reduced time on task for female learners in Session 2. In contrast, sustained motivation, as observed in male learners, was associated with improved performance over time. These insights underscore the necessity for the implementation of gender-sensitive gamification strategies that ensure long-term engagement for both genders.

6.2. Impact on performance

The hypothesis that gamification would lead to significant differences in learning performance between male and female learners was partially supported. No significant gender differences were

observed in overall performance metrics such as time on task and scores, indicating that both genders performed similarly regardless of gamification. However, detailed analysis revealed that males tended to score higher in the gamified condition compared to the standard condition in session one. Conversely, females initially spent more time on tasks in the gamified condition, but this engagement decreased in session two.

These findings highlight that while gamification can enhance performance for male learners, its effects on female learners may diminish over time, necessitating a revaluation of how gamification elements are designed and implemented to maintain engagement for all learners. This observation aligns with research showing that gamification significantly contributes to academic participation and influences learners' engagement in gamified environments (Zaric et al., 2021; Özhan & Kocadere, 2019). Flores (2016) and Wei et. al. (2024) discuss the role of educational games in boosting academic achievement and confidence, emphasizing the need for structured and interactive frameworks to sustain learner engagement.

6.3. Interaction effects on learning outcomes

The study also explored the interaction effects between session sequence and condition on learning outcomes, with results partially supporting the hypothesis to some extent. The repeated measures ANOVA revealed significant interaction effects for males' scores and females' time on task. Specifically, males showed lower scores in the standard condition compared to the gamified condition, while females exhibited higher engagement initially in the gamified condition but less so over time. These interaction effects underscore the importance of considering both the sequence and condition in designing gamified educational interventions. For male learners, introducing gamification early on might enhance performance, while for female learners, maintaining engagement might require varied or adaptive gamification strategies over time. This finding is consistent with research by Özhan & Kocadere (2019) and Kostolányová & Klubal (2018), which indicate that the design of gamified learning environments significantly influences academic participation and engagement.

6.4. Correlation analysis

The correlation analysis provided additional insights into the relationships between motivation and performance. For male learners, initial motivation before session 2 showed a non-significant trend toward a negative correlation with performance in session 1. Furthermore, better performance in session 1 was associated with less time needed in session 2. While these trends were not statistically significant, they suggest that highly motivated male learners may tend to work more efficiently. In contrast, female learners showed strong, significant correlations between motivation scores across sessions, indicating stable motivational levels regardless of condition. The moderate but non-significant correlations between time on task across sessions for females suggest a tendency toward consistent engagement patterns, emphasizing the potential role of initial motivation in sustaining engagement and performance. While these findings align with previous research highlighting the importance of intrinsic motivation in fostering student engagement and learning outcomes, the non-significance of several key correlations suggests that further investigation is needed. Tan (2018) and Khatoon (2023) emphasize the role of intrinsic motivation in fostering student engagement and its significant impact on learning outcomes.

6.5. Implications for educational practice

These findings have significant implications for the design and implementation of gamified educational technologies. Understanding the differential impacts of gamification on male and female learners can inform the development of tailored strategies to enhance engagement and learning outcomes. For female learners, incorporating varied challenges, adaptive mechanics and personalized feedback could help sustain interest over time, addressing the observed decline in motivation. For male learners, early introduction of gamification may provide a consistent boost to performance. These strategies align with existing literature on personalized learning and gamification (Buckley & Doyle, 2014; Martí-Parreño et al., 2016). Gamification leverages game elements to make learning more interactive, enjoyable, and rewarding, thereby fostering students' intrinsic motivation to participate in educational activities (Martí-Parreño et al., 2016). Additionally, research suggests that intrinsic and extrinsic motivation can impact student participation and performance in online gamified learning interventions (Buckley & Doyle, 2014).

7. Conclusion

The Basketball Physics Challenge study offers valuable insights into the impact of gamification on physics learning, highlighting its potential to enhance engagement and performance. However, the effects of gamification vary across genders and over time, and it is therefore important to tailor gamified educational tools to the needs of diverse learner demographics if optimal effectiveness and educational outcomes are to be achieved. This study emphasises the importance of considering gender differences in designing gamified learning tools and demonstrates gamification's potential to sustain engagement in educational settings. However, the findings should be considered in the context of the study's limitations, including the use of a small sample size and a focus on a single secondary school, which may affect the generalizability of the results. Future research should involve larger, more diverse samples and address the reliance on self-reported motivation measures by incorporating objective data, such as behavioural and physiological indicators. By addressing these limitations, future studies can provide deeper insights and robust evidence to guide the development of inclusive and effective gamified educational technologies.

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Biofeedback games in education: A review with implications for teacher training

Giochi di biofeedback nell'istruzione: una revisione con implicazioni per la formazione degli insegnanti

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ABSTRACT Biofeedback games use physiological feedback such as heart rate variability, electrodermal activity, breathing rate, and EEG data to help individuals improve awareness and control of their emotional responses. These tools have become increasingly recognized for their role in enhancing cognitive development, emotional regulation, and stress management. While biofeedback games have demonstrated substantial benefits in therapeutic contexts, their use in teacher training remains significantly underexplored. This review synthesizes the current research on biofeedback games, highlighting their therapeutic effects and cognitive benefits, followed by a discussion on their potential for application in teacher training settings. Through a critical disability studies lens, we propose the potential of these tools in supporting teachers' emotional well-being and reducing teacher burnout, thereby fostering more inclusive learning environments. The review concludes with the limitations of current research, along with recommendations for future studies to address the research gap and enhance teacher well-being and resilience through biofeedback interventions.

KEYWORDS Biofeedback Games; Teacher Training; Gamification; Inclusive Education; Emotional Regulation.

SOMMARIO I giochi di biofeedback utilizzano feedback fisiologici come la variabilità della frequenza cardiaca, l'attività elettrodermica, la frequenza respiratoria e i dati EEG per aiutare le persone a migliorare la consapevolezza e il controllo delle proprie risposte emotive. Questi strumenti sono diventati sempre più riconosciuti per il loro ruolo nel migliorare lo sviluppo cognitivo, la regolazione emotiva e la gestione dello stress. Sebbene i giochi di biofeedback abbiano dimostrato benefici sostanziali in contesti terapeutici, il loro utilizzo nella formazione degli insegnanti rimane significativamente sottoesplorato. Questa recensione sintetizza l'attuale ricerca sui giochi di biofeedback, evidenziandone gli effetti terapeutici e i benefici cognitivi, seguita da una discussione sul loro potenziale di applicazione nei contesti di formazione degli insegnanti. Attraverso la lente degli studi critici sulla disabilità, proponiamo il potenziale di questi strumenti nel sostenere il benessere emotivo degli insegnanti e nel ridurre il burnout degli insegnanti, favorendo così ambienti di apprendimento più inclusivi. La revisione si conclude con i limiti della ricerca attuale, insieme a raccomandazioni per studi futuri per colmare il divario della ricerca e migliorare il benessere e la resilienza degli insegnanti attraverso interventi di biofeedback.

PAROLE CHIAVE: Giochi di Biofeedback; Formazione degli Insegnanti; Gamificazione; Educazione Inclusiva; Regolazione Emotiva.

1. Introduction

Significant shifts and demands have come alongside Education 4.0 and the movement into a digital era (Bonfield et al., 2020; Hussin, 2018) which challenges traditional educational methods and approaches. Within this, the integration of gamification into education contexts has gained significant momentum (Lampropoulos & Kinshuk, 2024). Gamification, defined as "the use of game design elements in non-game contexts to motivate and increase user activity and retention" (Deterding et al., 2011, p. 9), stands as a powerful tool in modern educational settings through its ability to engage learners (Smiderle et al., 2020). By fostering motivation (Ratinho & Martins, 2023) and providing more interactive, personalized learning experiences, gamification has become a rapidly growing trend within innovative educational methodologies. A more recent development within this trend is the rise of biofeedback games, which use physiological data like heart rate variability (HRV) and electrodermal activity (EDA), as well as brainwave activity (EEG) in neurofeedback games, to give users real-time feedback on their emotional and physical states. Although biofeedback games have been explored for their use as tools for improving attention (Mercado et al., 2021), emotional regulation (Jerčić & Sundstedt, 2019), cognitive development (Liu et al., 2014), and stress management (Zafar et al., 2020), their use within teacher training remains largely unexplored.

Teaching is widely recognized as a highly demanding position, with educators increasingly leaving the profession (Madigan & Kim, 2021b) due to issues such as burnout (Brackett et al., 2010) and stress (Turner & Garvis, 2023). These issues not only have a direct impact on teachers' own socio-emotional well-being (Dreer, 2024) but also on student outcomes (Madigan & Kim, 2021a), making stress management and emotional regulation critical for effective teaching. Despite the importance of teacher well-being, there has been limited discussion on how elements of gamification with biofeedback could benefit teachers. Biofeedback games that focus on stress management and anxiety reduction could offer teachers valuable strategies by promoting emotional awareness and stress regulation. These benefits are also particularly relevant during the early stages of their careers when training is typically accompanied by heightened anxiety (Bilali, 2012; Morton et al., 1997; Paker, 2011). Incorporating these games into teacher training programs could help equip educators with lifelong practical strategies to manage stress and create more emotionally safe and supportive learning environments.

This review aims to address the existing gap in the literature by exploring the current state of research on biofeedback games in therapeutic and cognitive-enhancing contexts, along with a discussion on the important implications and potential uses of biofeedback games in teacher training and professional development programmes. Through a comprehensive search of the literature, this review will explore the potential benefits of incorporating biofeedback games into teacher professional development programs, especially in fostering emotional regulation and stress management strategies. While biofeedback games have demonstrated theoretical promise in teacher training, the current body of literature is limited by a lack of direct empirical studies showcasing their effects in naturalistic educational settings. This review synthesizes existing research, but pilot studies or case studies from diverse contexts are necessary to provide concrete evidence for their efficacy in real-world applications. Grounded in the theoretical framework of Critical Disability Studies (CDS), this review will explore how integrating biofeedback games for teachers, rather than only for students, aligns with more inclusive educational approaches. CDS challenges conventional understandings of disability by advocating for educational systems that accommodate the diverse needs of learners, rather than requiring students to conform to standardized norms. This perspective will inform the implications for teacher training,

recognizing that emotionally regulated teachers play a crucial role in creating responsive, safe learning environments. By adopting a holistic view of the inclusive classroom, this approach emphasizes the meaningful use of technology, not just for students, but for teachers as well, acknowledging them as central figures for defining classroom dynamics.

2. Background

2.1. Gamification

Gamification involves integrating game mechanics into non-game environments such as education, business, or healthcare (Wood & Reiners, 2015) to enhance user motivation and engagement, which in turn improve the relevant learning or health outcomes (Manzano-León et al., 2021, Rivera & Garden, 2021). Gamification in education involves key elements such as engaging challenges, interactivity, and continuous feedback (Díaz & Troyano, 2013; Kapp, 2012; Zichermann & Cunningham, 2011). Mechanics like levels and badges reward achievement, while appealing aesthetics enhance user experience. Games can involve problem-solving to assist users in acquiring new skills through gameplay. Different player types are considered to ensure motivation, and learning is promoted through points and corrective feedback. Rewards include point systems, level progression, badges, tangible rewards, leaderboards, and challenges, all designed to motivate students and track their progress (Rodríguez-García & Gómez-García, 2020). Also, gamification promotes collaboration among users, stimulating cooperation and teamwork, and making the learning process more social (Floris et al., 2024).

2.2. Biofeedback games

Biofeedback is a technique that helps individuals learn to control physiological processes that are typically involuntary (Tosti et al., 2024). Biofeedback works by converting physiological signals into visual and auditory cues that are then, in real-time, shown back to the user (Frank et al., 2010), creating a feedback loop to encourage better self-awareness and control over these physiological reactions and arousal states. Biofeedback, as a therapeutic approach, provides users with real-time information about their physiological processes that help them develop increased understanding and improved self-regulation. The idea is that when combined with emotional or behavioural interventions, this awareness can assist in a change in the physiological process, with the aim that newfound control can be maintained further down the line without the equipment (Kondo et al., 2019; Peper, 1979). This process has been used for a wide variety of different conditions (Giggins et al., 2013; Kondo et al., 2019; Schoenberg & David, 2014).

Although biofeedback is a valuable tool for enhancing self-awareness and emotional regulation, its physiological conceptions and the mechanisms behind it could be challenging for many individuals to understand intuitively. Parnandi & Gutierrez-Osuna (2021) explain that gamified biofeedback is "a form of instrumental conditioning in which reinforcements (i.e., rewards or penalties in the game) are used to modify voluntary behaviours (e.g., increase or decrease breathing rate)" (Parnandi & Gutierrez-Osuna, 2021, p. 141). The sensors track the player's emotional states during gameplay, allowing the game to adjust and provide rewards for actions that encourage relaxation (Parnandi et al., 2014; Parnandi & Gutierrez-Osuna, 2021). Thus, serious games serve as an effective bridge (Jerčić & Sundstedt, 2019; Parnandi & Gutierrez-Osuna, 2015; Stapleton, 2004), and in this context provide interactive environments that contextualize bio- and neurofeedback data (Lüddecke & Felnhofer, 2022; Vinod

& Thomas, 2018) to facilitate the real-time perception of emotional responses reflected in physiological changes. By transforming the concepts of biofeedback into engaging gameplay, these serious games help users better recognize and manage their internal physiological states and emotions, in a more streamlined way.

Biofeedback games combine the biofeedback techniques with interactive game elements, providing a dynamic way to learn self-regulation. Gamification plays a critical role here by increasing motivation and engagement, which can be particularly valuable in educational and therapeutic settings. In contrast to biofeedback as a standalone technique, gamified biofeedback incorporates fun, interactive elements to increase motivation to practice self-regulation techniques, with research demonstrating its promise in aiding skill acquisition and transfer (Parnandi & Gutierrez-Osuna, 2017).

3. Theoretical framework

The theoretical framework and approach we adopt for the conception of this paper is grounded in Critical Disability Studies (CDS) which redefines how we perceive and address disability. Instead of focusing on individual impairments, critical disability theory emphasizes the social, cultural, and institutional factors that contribute to the lived experience of disability (Campbell, 2010; Goodley, 2013; Meekosha & Shuttleworth, 2009). This perspective is critical within educational and therapeutic contexts, and when assessing the potential role and benefits of biofeedback games. As assistive technologies, the use of these biofeedback games can either challenge or reinforce existing power dynamics and accessibility issues, depending on how they are implemented. An inclusive education system, as Hoogerwerf describes, "supports all of its students to access, participate in, and benefit from an appropriate education" (Hoogerwerf et al., 2021, p. 1). This means that systems must adapt to meet the diverse needs of all learners, rather than problematising or "othering" (Barnes, 1992; Manchanda, 2024; Reutlinger, 2015; Saltaga, 2017) disabled students and placing the onus on them to conform to rigid norms. Truly inclusive integrations of assistive technologies, such as biofeedback games, lie in their thoughtful, meaningful use (Connor & Beard, 2015), and the principle of designing these technologies "with and for" (Motti, 2019) users is essential. When implemented in this way, biofeedback games have the potential to create adaptive, responsive environments that benefit all users, especially those with diverse needs.

Moreover, the role of teachers in the meaningful implementation of these technologies cannot be overlooked. Pérez (2014) stresses that teachers are key figures in ensuring that assistive technologies are effectively integrated into the classroom. However, not only must teachers be equipped with sufficient knowledge and skill in using such innovative tools, but teachers must also be emotionally regulated to maintain an inclusive and emotionally safe environment. This is particularly pertinent for neurodiverse students who rely more on others for emotional regulation (Cibralic et al., 2019), thus require emotionally safe and predictable adults. However, practising effective emotional regulation is something that can be difficult within systems that are increasingly requiring more emotional labour and leading to burnout (Kariou et al., 2021). A CDS framework also stresses systemic and structural factors that influence teacher well-being, rather than placing stress management solely as an individual responsibility. This aligns with the review's aim to propose the potential of bio- and neurofeedback games as necessary in stressful teaching environments. By acknowledging the broader institutional pressures and expectations that contribute to teacher stress and burnout, these tools can support the creation of inclusive educational practices.

Regulated adults are fundamental to creating an inclusive classroom, as they help shape an emotionally safe environment in which students can thrive emotionally (Frenzel et al., 2021) and academically (Pi et al., 2022). Thus, this review proposes that biofeedback games should not only be used to support students but also to encourage emotionally regulated teachers. In doing so, it is more possible to ensure that the integration of such technologies is both meaningful and aligned with the principles of truly inclusive education and critical disability studies, which advocate for systemic change rather than superficial fixes.

4. Methodology

4.1. Search strategy

This review employed a comprehensive search strategy to identify relevant research on biofeedback games in education, utilizing two major databases: Web of Science and Scopus. Search queries included combinations of terms such as 'biofeedback games,' 'neurofeedback games,' with 'education,' 'learning outcomes,' 'student engagement,' and 'teacher training.' Additionally, the review incorporated terms related to stress, anxiety, and emotion regulation, such as 'relaxation,' 'stress management,' and 'anxiety'. The decision to include these additional terms was made to understand the uses of biofeedback games not only for traditional educational outcomes but also for supporting emotional well-being. Emotional regulation and the management of stress and anxiety impact learning and engagement for both students and teachers. Emotion regulation is key in creating inclusive, supportive classroom environments, making it an essential area to include in this review. The decision not to restrict the search to specific clinical or non-clinical populations was based on the intent to provide a comprehensive understanding of the application of biofeedback games across diverse contexts, followed by a discussion on how such applications and the findings have implications for teacher training contexts. No date limits were set to gain a complete and thorough overview of biofeedback games and their use in education. Language filters were applied to include only English and Italian publications.

4.2. Search results

Initially, the Web of Science[1] and Scopus[2] database searches yielded a combined total of 116 results. A detailed screening of titles and abstracts was conducted to identify titles and abstracts that included

[1] Full Web of Science search query: "biofeedback games" OR "neurofeedback games" OR "biofeedback game" OR "neurofeedback game" OR "biofeedback educational game" (Topic) and "emotion regulation" OR "stress management" OR stress OR anxiety OR depression OR emotion* OR "emotional regulation" OR Education OR Learning OR Teaching OR Pedagogy OR Instruction OR Curriculum OR "Educational technology" OR Classroom OR "Educational tools" OR "Learning outcomes" OR "Educational strategies" OR "Teacher training" OR "Educational policy" OR "Education reform" OR "Distance learning" OR "Blended learning" OR "Online learning" OR E-learning OR "Learning environments" OR "Formal education" OR "Non-formal education" OR "Informal education" OR "Learning styles" OR "Experiential learning" OR "Constructivist learning" OR "Collaborative learning" OR "Active learning" OR "Critical thinking" OR "Problem-solving" OR Creativity OR "Metacognition" OR Motivation OR "Student engagement" OR "Self-directed learning" OR "Personalized learning" OR "serious games" (Topic)

[2] Full Scopus search query: (TITLE-ABS-KEY("biofeedback games" OR "neurofeedback games" OR "biofeedback game" OR "neurofeedback game" OR "biofeedback educational game") AND TITLE-ABS-KEY("emotion regulation" OR "stress management" OR stress OR anxiety OR depression OR emotion* OR "emotional regulation" OR Education OR Learning OR Teaching OR Pedagogy OR Instruction OR Curriculum OR "Educational technology" OR Classroom OR "Educational tools" OR "Learning outcomes" OR "Educational strategies" OR "Teacher training" OR "Educational policy" OR "Education

terms that were focused on the theme of biofeedback games within educational and therapeutic contexts. This screening reduced the number of relevant articles to 78. Following importation into reference managing software Zotero, 30 duplicate or non-accessible results were removed which left the remaining 48 articles ready for full-text review. The full-text review involved identifying articles that were relevant to the review's objective, using the inclusion criteria. The inclusion criteria are outlined as follows: articles must involve bio- or neurofeedback games and explicitly discuss their application within therapeutic outcomes, cognitive-attentional interventions, or educational and learning contexts. Articles not meeting these themes were excluded. Additionally, articles that focused solely on bio- or neurofeedback without a gamification element were excluded, for example, articles that were regarding neurofeedback but not relevant to gamification, were not included in the review. Full-text screening resulted in a further 17 articles being excluded, leaving 31 articles to be synthesised. Publications covering broader clinical populations were included to explore their relevance to the therapeutic outcomes, such as stress management or cognitive improvements, which may also hold implications for teacher training. This decision was aimed at bridging the gap between existing evidence in clinical contexts and potential applications in educational settings, which is explored in more detail in the discussion. The review process involved an evaluation of the studies' methodologies, findings, and relevance.

4.3. Data synthesis

Regarding the data synthesis process, information pertaining to the methodologies, key findings, implications and conclusions were extracted. These findings were then synthesised into the 4 key themes:

- Biofeedback games for stress management
- Biofeedback games for supporting neurodiversity
- Biofeedback games for cognitive development
- Biofeedback games for anxiety and other mental health conditions

The data synthesis process included a thematic analysis to identify recurring patterns across the diverse studies and contexts of this relatively niche topic with limited data. This allowed for the integration of findings from both clinical and non-clinical populations into broader categories relevant to the present teacher training contexts. This review conducts a thorough analysis and critical evaluation of the included studies through the lens of CDS. These findings preceded a wider discussion on their implication in teacher training, and how the results from implementations of biofeedback games within the contexts of the research could also be integrated into teacher training programmes. This approach seeks to address existing gaps in the literature and contribute to the development of more inclusive and adaptive practices, as well as to identify the potential benefits and challenges of integrating them into training programs for the promotion of stress management techniques and the prevention of teacher burnout.

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reform" OR "Distance learning" OR "Blended learning" OR "Online learning" OR E-learning OR "Learning environments" OR "Formal education" OR "Non-formal education" OR "Informal education" OR "Learning styles" OR "Experiential learning" OR "Constructivist learning" OR "Collaborative learning" OR "Active learning" OR "Critical thinking" OR "Problem-solving" OR Creativity OR "Metacognition" OR Motivation OR "Student engagement" OR "Self-directed learning" OR "Personalized learning" OR "serious games"))

5. Results

5.1. Overview of included studies

A total of 31 studies were reviewed, focusing on the application of biofeedback games across socio-emotional, cognitive, and therapeutic contexts. The studies ranged from 1998 to 2024, but due to being a relatively novel concept, most of the research has emerged in the last 8 to 10 years. Sample sizes were typically small, although some confirmatory, slightly more higher-powered studies involved samples of up to 100 participants. Participants across the studies varied widely in age, including children with special educational needs, adolescents, young adults, as well as healthy adults. Any conditions addressed included anxiety, depression, ADHD, autism, and other neurodiverse conditions. The reviewed studies used various biofeedback or neurofeedback systems of differing physiological aspects. Many studies demonstrated promising outcomes, such as improved emotional regulation, enhanced cognitive skills, and reduced anxiety, with some showing positive carry-over effects on subsequent stressful or cognitively demanding tasks. Further research is recommended to validate these findings with larger and more diverse populations.

5.2. Biofeedback games for stress management

The review revealed that biofeedback games have shown significant potential for promoting stress regulation and relaxation by providing real-time feedback on physiological data. The feedback loops in these games usually reward relaxing behaviours and penalize states of high arousal, reinforcing stress-management techniques. For example, Parnandi et al., (2014) assessed an adaptive biofeedback game that tracked breathing rate, HRV, and electrodermal activity (EDA), using a positive feedback loop which encouraged users to maintain relaxed states. They found that the biofeedback game lowered arousal during a subsequent stress-inducing task. Similarly, Condron et al. (2009) used two bio-electric sources: GSR and EEG to promote relaxation, with the results demonstrating the utility of biofeedback for stress reduction in a sample of 14 people aged between 20 and 40 years.

Several studies also demonstrate the carry-over effect of these results, where relaxation skills developed during engagement with biofeedback games are successfully transferred to subsequent, cognitively stressful tasks. Zafar et al. (2017, 2020) in studies of samples of 42 and 100 participants, respectively, found that biofeedback games that focused on breathing control not only improved performance during gameplay but also helped users regulate their breathing and manage stress in post-game stress-inducing tasks. In their studies, participants who played biofeedback-enhanced games exhibited better cognitive performance and lower stress arousal during these follow-up tasks, compared to those who played non-biofeedback versions. As well as this, in comparison to the control group, the biofeedback enhancement also improved attentional-cognitive performance in the following task. This suggests that biofeedback games do more than just reduce stress temporarily, they help users acquire longer-term skills in both stress management and cognitive performance, in an engaging and motivating way through the use of game elements. However, it is worth noting that the participants in both studies were exclusively male, which limits the generalisability of the results. This carry-over effect was further supported by Wollmann et al. (2016), who explored how gamified HRV biofeedback enhanced user engagement with breathing exercises, improving motivation and adherence. Together, these studies illustrate the broad applicability of biofeedback games in helping users manage stress not just in real-time, but in the long-term too.

Biofeedback game relaxation-based benefits have also been highlighted within therapeutic contexts. Leahy et al. (1998) applied biofeedback games to teach relaxation techniques to irritable bowel syndrome (IBS) patients, showing significant improvements in stress management. More recently, Burkhart et al. (2018) applied biofeedback games in combination with psychoeducation on the effect of stress, diaphragmatic breathing, and progressive muscle relaxation in younger populations within an adolescent medicine clinic. At post-intervention, they reported a clinically significant decrease in subjective distress, providing important implications for the use of biofeedback games to enhance traditional interventions. This showcases the benefits of game-based intervention as opposed to standard interventions. These results align with findings from Dillon et al. (2016), who within 50 participants aged between 18-35 found that skin-conductance biofeedback combined with gaming-style smartphone applications significantly improved stress and heart rate levels in comparison to the control group.

Mobile biofeedback apps also present a promising, accessible approach to stress management, especially as app-based gaming offers increased accessibility and familiarity for a large portion of users. For instance, Almeqbaali et al. (2022) reported the effectiveness and ease of use of a mobile biofeedback app designed by mental health professionals to help young adults with anxiety. Moreover, Chand & Khosla (2022) showed how affordable, open-source systems like the Nintendo Entertainment System (NES) could gamify biofeedback, enhancing engagement and mental relaxation through higher HRV, indicating lower stress. This demonstrates how biofeedback games can meet the demands of a variety of populations and users through accessibility and affordability.

5.3. Biofeedback games for supporting neurodiversity

Several studies included in the review demonstrated how biofeedback games also show promise for supporting neurodivergent populations, particularly in attention regulation and social support. For individuals with attention deficit hyperactivity disorder (ADHD), a neurofeedback game shows promise in enhancing focus and attention, as shown in a study of adults with ADHD by Ochi et al. (2017), though it is worth noting the study was a pilot.

Further, gamified neurofeedback for increasing adherence to treatment due to the collaborative and engaging nature of these games has also been proposed for children with ADHD (Arrambide et al., 2019). For autistic children, neurofeedback games have been proposed to support social and attentional capabilities, Yang et al. (2021) conducted a neurofeedback training (NFT) game using EEG-based neurofeedback in special education centres. The researchers highlighted the importance of involving both the children and their caregivers and parents to gain deeper insight into the experience of the children given the individual differences and challenges of communication (p.8, Yang et al., 2021).

5.4. Biofeedback games for cognitive development

A further key application of biofeedback games was found to be in enhancing cognitive skills and promoting emotional competence. Echoing the improved attentional-cognitive performance findings from Zafar et al. (2017; 2020), Suhail & Vinod (2024) explored how neurofeedback games could improve attention and working memory in healthy individuals, finding an improvement as a result of the non-violent neurofeedback game sessions. Repeating the sentiments of Chand & Khosla (2022), the authors also highlighted the low cost of the wireless EEG system, suggesting its comfort and convenience as factors for smooth dissemination into non-laboratory contexts (p.490, Suhail & Vinod, 2024).

Looking towards cognitive enhancement within a language learning context, Chang et al. (2020) focused on auditory discrimination using an event-related potential game, where participants significantly improved in differentiating speech sounds in a foreign language.

5.5. Biofeedback games for anxiety and other mental health conditions

Several studies support the efficacy of biofeedback games in managing anxiety, depression, and other mental health conditions. Weerdmeester et al. (2021) used a VR biofeedback game called DEEP, which significantly reduced anxiety levels in a group of undergraduates. This game increased participants' self-efficacy, and its effects on anxiety persisted over three months. Biofeedback games have also been employed to address depression. Cai et al. (2017) explored a VR neurofeedback game for individuals with depression, finding that it enhanced their motivation to engage in therapy. Similarly, Rockstroh et al. (2021) showed how biofeedback training for diaphragmatic breathing in a VR environment helped decrease burnout symptoms and boost relaxation-related self-efficacy in participants. Furthermore, biofeedback games were shown to support emotional regulation in a variety of different settings. Haneveld et al. (2023) investigated the use of VR biofeedback for diaphragmatic breathing in forensic psychiatric patients, showing its potential to help individuals manage negative emotions. The results demonstrated how DEEP offered innovative methods to support users, though the inability to personalize the game hindered long-term engagement, which is an important consideration for future implementations.

6. Discussion: implications for teacher training

The goal of this review was to use the findings of a review of applications of biofeedback games in diverse settings to showcase the increasing potential of biofeedback and neurofeedback games as tools for emotional regulation, cognitive development, and stress management in teacher training contexts. As mentioned, the present state of the literature surrounding the topic is limited, thus in the following discussion we offer proposals for potential implications. Biofeedback games have shown promising outcomes across various populations and contexts, such as enhancing attention in neurodiverse groups, improving relaxation in therapeutic settings, and reducing anxiety and stress through real-time physiological feedback. However, there is a noticeable gap in the application of biofeedback games within teacher training programs, where such tools could play an essential role. This discussion will explore the implications for teacher training.

6.1. Emotion regulation and stress management in teacher training

The results from the review support the proposal that integrating biofeedback games into teacher programmes could significantly benefit not only the teachers themselves but also the students. These games, which were shown to be successful in anxiety and stress management (Almeqbaali et al., 2022; Burkhart et al., 2018; Chand & Khosla, 2022; Condron et al., 2009; Dillon et al., 2016; Parnandi et al., 2014; Weerdmeester et al., 2017; Wollmann et al., 2016; Zafar et al., 2017, 2020), could be highly beneficial in teacher training. As mentioned previously, early-career teachers often experience high levels of stress. Incorporating biofeedback games into teacher training programs can help educators develop emotional regulation skills, increasing their resilience to classroom stressors and preventing burnout.

Teacher's emotional regulation and well-being are linked to their job retention (Sadraei et al., 2024), and while biofeedback games improve emotional well-being and help with stress management – indirectly easing burnout – the study by Rockstroh et al. (2021) is particularly significant. It directly shows a reduction in burnout symptoms, positioning biofeedback as not just a tool for emotional regulation but as an effective intervention for combating teacher burnout. As well as this, teachers who are better able to manage their emotions in turn create more emotionally safe and inclusive learning environments. Biofeedback games could enhance teachers' self-awareness and emotional control, which has positive implications for classroom management and student outcomes.

As mentioned, a key principle of CDS is the acknowledgement of systemic and structural pressures that teachers face and that ultimately drive stress and burnout. Integrating biofeedback games into teacher training programs offers an opportunity to address these pressures, providing teachers with tools to navigate and critique these conditions as opposed to placing teacher stress as a personal defect or inability to manage the career**.** This perspective demands a shift from an individual-focused narrative to one that acknowledges the broader systemic and organizational contexts, as well as highlighting the importance of teachers' emotional well-being for themselves and students alike. Furthermore, the application of biofeedback games in teacher training could foster collective well-being and coregulation by promoting shared emotional regulation strategies within educational institutions, which nurtures positive student-teacher interactions (Aldrup et al., 2024), and student success (Braun et al., 2020; Sáez-Delgado et al., 2022.

However, despite the potential of incorporating biofeedback games within teacher training programmes, practical barriers such as the costs of equipment remain significant obstacles, particularly in higher education (Leontyeva, 2018). Not only would higher education institutions need to afford the costs of the equipment, but there would also be financial needs for the training of the teachers to use the equipment. Nevertheless, biofeedback sensors are becoming increasingly available and with relatively simple designs stand as optimal non-invasive technologies.

6.2. Cognitive skills enhancement for professional development

The findings from the review which related to cognitive development also have key implications for teacher training programmes. The review highlighted biofeedback games as valid supports for attentional-cognitive performance (Ochi et al., 2017; Zafar et al., 2017, 2020), as well as for working memory (Suhail & Vinod, 2024). This has implications for teacher training as this could mean that they might be more effective in their teaching roles, which would lead to better learning outcomes for students. Improved attentional and cognitive abilities may also enable teachers to engage with students more effectively, fostering a positive classroom environment that enhances overall educational experiences. Additionally, equipping teachers with enhanced cognitive skills may empower them to adapt their instructional strategies to meet diverse student needs. Within the CDS framework, professional development through the use of cognitive training technologies like biofeedback games stand as tools that are incorporated into systemic teacher training curriculums, rather than merely supporting individual teacher performance.

Moreover, the review also found biofeedback games to be connected to self-efficacy (Rockstroh et al., 2021; Weerdmeester et al., 2017). Improvements in one's ability to manage their autonomic responses and emotional regulation may improve well-being and self-efficacy. In teaching contexts, self-efficacy has been suggested to not only be important for teaching skills (Walter, 2015), and efficacy (Karim

et al., 2021) but also for preventing burnout (Friedman, 2003; Li, 2023). Thus, biofeedback training, through its ability to contribute to the management of emotions, could have implications for enabling teachers to feel more competent in their abilities, ultimately leading to improved job satisfaction. If teachers feel more confident in their roles, they may be more equipped to cope with the challenges of teaching, positively impacting their well-being, as well as that of their students. This creates a more resilient teaching workforce, as well as more emotionally safe and supportive learning environments.

The findings from the included studies also included support for the gaming element of biofeedback games to increase adherence to treatments due to increased engagement, this has relevant implications for biofeedback games within teacher training as teachers may be more inclined to use biofeedback techniques if they are more accessible and appealing.

The review highlights the importance of participatory design in biofeedback technologies, which is a principle rooted in CDS. Applying this principle within teacher training programs ensures that biofeedback games are tailored to the specific needs and experiences of educators, including those from marginalized or underrepresented backgrounds. This approach not only enhances the usability of these tools but also reinforces their alignment with inclusive and adaptive educational practices.

7. Limitations and future research directions

In a discussion of the potential of biofeedback games in teacher training, it is crucial to also address the methodological limitations in the existing research. One major limitation is the small sample sizes in many of the studies, utilising homogenous groups, sometimes exclusively male participants, thus limiting the generalisability of the findings. Additionally, though some studies pointed to the system usability and convenience of the biofeedback training game (Chao et al., 2023; Suhail & Vinod, 2024), the controlled lab settings in which a major part of the studies were conducted raises questions about how well these games would perform in the real-world settings. One study highlighted system resilience to sensor movement and noise in a non-laboratory environment (Flowers et al., 2018), an important consideration due to the commonality of disruptions in classroom and non-controlled environments.

Many of the reviewed studies focused on biofeedback's use in therapeutic contexts, such as anxiety management and emotional regulation for specific populations. While this highlights biofeedback's potential for improving mental health, the use of penalisation within the games to encourage users to adapt their responses could be reflective of the medical model approach that seeks to 'normalize' or 'correct' behaviour. One study highlighted this further, reporting that within neurofeedback games, positive reinforcement is more effective than negative reinforcement (Reinschluessel et al., 2016). Moreover, it is important to consider the broader systemic or social stressors teachers face, an area that CDS emphasises. Through this lens, biofeedback games should empower teachers to manage stress and personal regulation, whilst considering also external, systemic stress factors.

Ethical considerations related to the implementation of biofeedback games in educational settings are also important to highlight. The continuous collection of biometric data could exacerbate stress or anxiety for some teachers. It is important that future implementations address these potential risks by using strict protocols for data privacy and security, as well as transparency in how the data is used. Schools and researchers must carefully consider and navigate these concerns to avoid inadvertent psychological harm.

Furthermore, one study examining a neurofeedback game found only marginal evidence supporting the game's claims (Coenen et al., 2020), underscoring the need for validation before widespread

implementation. This is especially important when using these technologies with disabled or vulnerable groups to ensure, as mentioned earlier, they are used in a thoughtful, meaningful way (Connor & Beard, 2015). Additionally, the cost and accessibility of biofeedback tools present barriers for schools with limited funds or educators operating in resource-constrained environments. There remain important questions about not only how to ensure equitable access to these technologies across diverse educational contexts, but also how to sufficiently train teachers to use such tools.

A significant limitation of existing research is the narrow scope of participant demographics, due to the limited existing data, sample sizes are generally small and homogenous. Future investigations should aim to recruit larger and more diverse populations, accounting for socio-economic and cultural differences to enhance the generalisability of findings. Future research should focus on developing and testing biofeedback games designed specifically for teachers, using larger and more diverse sample sizes to ensure the generalisability and validity of the results. It will also be important to assess the long-term effects of these tools on teacher performance, emotional regulation, and student outcomes, as well as their integration into daily pedagogical practices. Longitudinal studies are necessary to assess the long-term effects of biofeedback on teacher well-being, classroom performance, and student outcomes. Additionally, future game designs should prioritize positive reinforcement mechanisms to enhance user engagement and outcomes (Reinschluessel et al., 2016).

8. Conclusion

Though in the early stages biofeedback games offer an innovative and promising approach to both education and therapeutic contexts. By integrating gamification with biofeedback, these games provide an engaging and effective way to enhance socio-emotional skills, cognitive abilities, and self-regulation techniques. As research on biofeedback games continues to expand, their potential to support stress management and emotional resilience within teacher training programs increases, and access to these games becomes more widely available. However, as the field continues to grow, and biofeedback games become more accessible, it is essential to validate findings within diverse educational, and teacher training contexts.

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10. Authors’ contributions

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