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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.

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

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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 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.

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

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

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) 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.

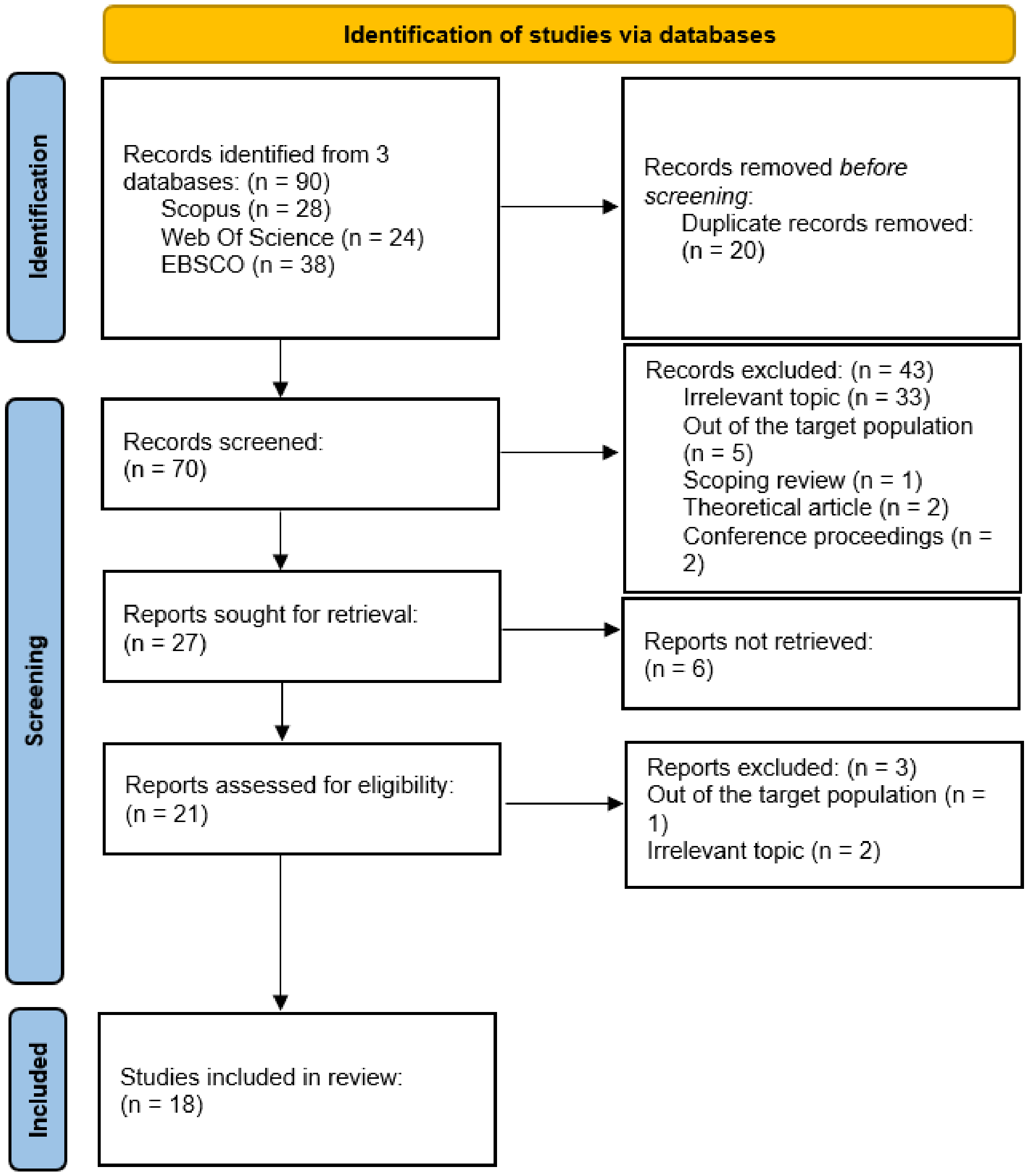

Figure 1. PRISMA flow chart of the selection process.

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

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	Ireland	Primary school students (n=885)	Geography, spatial planning	Six weekly teacher-facilitated Minecraft	Mixed methods	Improvements in spatial thinking

	intervention for improving spatial thinking in primary school children: A mixed methods two-level cluster randomised trial			and spatial thinking	Education sessions with guided spatial thinking challenges over 6-8 weeks		
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	Ireland	Primary and middle school students (n=173)	Students' perspective	Used in a national project combining educational episodes and a sustainability-	Mixed methods	Identification of benefits in using Minecraft as an educational tool

	during a National Project-Based Initiative: An Irish Study				focused competition		
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
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
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 Programmin g to Younger Students	Alabama, USA	Educational game intended for PK-8 grades (kindergarte n, primary school and middle school students) (n=n.a.)	Teaching programmin g	Used as a game environment for teaching Python programming	Design case study	Developmen t of a Minecraft-based educational game to teach the basics of Python programmin g
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	Netherlan ds	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	Quantitativ e methods	Analysis of students' emotional engagement when using Minecraft for spatial planning

Spatial Planning with Minecraft	

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. 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 prominent 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, reinforcing 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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The authors declare no conflict of interest.

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