European Journal of Science and Mathematics Education, 2025, **13**(4), 336-351
ISSN: 2301-251X (Online)

OPEN ACCESS

Review Article

Video games and key competencies' development in STEM areas: A systematic review

Alejandra Ramírez-Segado [1]
0000-0002-9547-6647

Alicia Benarroch [1]
0000-0003-0316-0141

Francisco Javier Carrillo-Rosúa [1]
0000-0003-2889-3966

David Aguilera [1*]
0000-0002-7996-9097

[1] Department of Science Education, Faculty of Education Sciences, University of Granada, Granada, SPAIN
[*] Corresponding author: davidaguilera@ugr.es

Citation: Ramírez-Segado, A., Benarroch, A., Carrillo-Rosúa, F. J., & Aguilera, D. (2025). Video games and key competencies' development in STEM areas: A systematic review. *European Journal of Science and Mathematics Education, 13*(4), 336-351. https://doi.org/10.30935/scimath/17409

ARTICLE INFO

Received: 23 Apr 2025

Accepted: 3 Oct 2025

ABSTRACT

The present study aims to review the state of the art regarding the use of video games (VGs) in science, technology, engineering, and mathematics (STEM) education and to analyse their implications for students' competency development in STEM areas. A systematic review was conducted following the preferred reporting items for systematic reviews and meta-analyses guidelines, focusing on studies indexed in the Web of Science and Scopus databases between 2015 and 2024. The results indicate that most of the analysed VGs are specifically designed for educational purposes, are geared towards the teaching and learning of a STEM discipline and cater to all levels of cognitive complexity. Regarding the impact of VGs on competency development, their technical features appear to exert a greater influence than their pedagogical aspects. Finally, this study highlights the transformative potential of VGs in STEM education and underscores the need for further research to expand their applicability across different educational stages, examine the risks associated with their use, and ensure their sustainability and accessibility in diverse educational contexts.

Keywords: video games, STEM education, abilities, cognitive demands

INTRODUCTION

The literacy of citizens in science, technology, engineering, and mathematics (STEM) fields has become a socio-educational issue of particular relevance and interest worldwide (Kayan-Fadlelmula et al., 2022). In response, many educational systems have promoted STEM education–understood as the collective reference to the four specific didactics involved (Johnson et al., 2021)–has been pursued with the aim of developing new talent equipped with the skills required to thrive in the 21st century, such as computational thinking, critical thinking, and creativity (Wahono et al., 2020). To support this goal, various countries consider literacy in STEM fields a national priority in their basic education reforms (Dou, 2019). This effort has been structured since the 1990s, generally through competency-based education systems (Ortiz-Revilla et al., 2021).

The OECD's (2003) project recommended adopting a functional approach to academic performance. Accordingly, the concept of competency should be understood as an integration of knowledge (cognitive dimension), skills (procedural dimension), and attitudes (affective dimension) to carry out a specific task. In line with this Valle and Manso (2013) assert that:

> Key competencies, therefore, represent three areas of development for learners: personal (they provide the essential foundation for individual growth and self-development), social (they equip individuals with the tools necessary to integrate into and actively participate in contemporary society in a creative manner, enabling them to contribute to the collective advancement of society), and professional (they allow individuals to acquire initial workplace qualifications and encourage continuous improvement in their professional trajectory) [own translation] (p. 26).

In this regard, educational institutions have undergone changes aimed at providing competency-based learning, which have impacted teaching practices. Within this framework, one of the most significant pedagogical innovations has been the digitalisation of teaching and learning processes. More specifically, digital game-based learning (DGBL) has emerged as one of the global pedagogical approaches of the 21st century (Kukulska-Hulme et al., 2024).

Digital games or video games (VGs) are defined as rule-structured, technology-mediated activities in which participants achieve predetermined outcomes (Martínez-Garza et al., 2013). In this way, VGs create active learning environments that differ from simulators and other gamified technological resources in three key aspects:

(1) they incorporate mechanisms specifically designed to enhance enjoyment and engagement (known as "game mechanics"),

(2) the rules and objectives of the game are explicitly shared with the user, and

(3) they employ a scoring or reward system that clearly informs players of their progress (Martínez-Garza et al., 2013).

Building on this distinction, Mayer (2014) distinguished educational VGs, or serious games, from commercial VGs due to their explicit intent to promote learning among players. As a result, serious games go beyond entertainment (Lameras et al., 2017). In this vein, Gui et al. (2023) have identified three pedagogical reasons that support the effectiveness of VGs in facilitating learning in STEM fields:

- From the perspective of situated learning (Lave & Wenger, 1991), serious games create a learning environment for the construction of new knowledge, where students can acquire and develop skills through the dynamics and mechanics of the game.
- This interactive environment could be conceived as a virtual community of practice that provides supportive guidelines (Klopfer & Thompson, 2020).
- Serious games incorporate pedagogical elements in their design (e.g., self-assessment strategies) that foster metacognition (Grivokostopoulou et al., 2020).

Despite the reservations expressed by some members of the educational community regarding the inclusion of VGs in classrooms, there is now a substantial body of knowledge that justifies and effectively articulates their implementation. This is evident in the various systematic reviews and meta-analyses published in recent years. For example, Brown et al. (2018) reviewed the state of the art concerning the use of VGs in university-level science education, with particular attention to microbiology. Likewise, Tsai and Tsai (2020) synthesised the published evidence on the effectiveness of DGBL for science education. Hussein et al. (2019) analysed the educational implications of DGBL in primary science education. With the same objective, Hussein et al. (2022) conducted another systematic review focusing on mathematics education at the primary and secondary levels. From a bibliometric perspective, Pan et al. (2022) described the research methodologies employed and the usage trends of VGs in mathematics education. Chen et al. (2022) reviewed the period 1991–2020 to identify the most influential authors in DGBL within science and mathematics education, as well as the regions where the most research was conducted, the most frequently used VG genres, and other sociodemographic variables. With a similar aim, Udeozor et al. (2023) conducted a systematic review to describe the state of the art regarding the use of VGs in engineering education. Meta-analytic studies further support the effectiveness of DGBL. Byun and Joung (2018) found significant improvements in mathematics learning through the DGBL approach compared to traditional pedagogical models. Following the same methodology but with a broader study perspective encompassing all STEM fields, Wang et al. (2022) identified that DGBL significantly enhances learning compared to traditional educational models, regardless of the STEM area or educational stage. They also observed that short-term DGBL interventions (less than a week) yield better results than longer interventions. Similarly, Gui et al. (2023) found that DGBL has a significantly greater overall effect than traditional educational interventions, highlighting that strategy-based VGs may enhance learning acquisition more effectively than other game genres.

METHODOLOGY

A systematic review has been conducted in accordance with the guidelines of the preferred reporting items for systematic reviews and meta-analyses (PRISMA) declaration, following its updated 2020 version (Page et al., 2021). The review process was implemented in six phases (Buntins et al., 2019), aligned with the following objectives:

(1) to review the state of the art regarding the use of VGs in STEM education and

(2) to analyse the characteristics of the VGs used in STEM education and their implications for students' competency development.

Phase 1. Research questions (RQ). Specific RQs were formulated to achieve the stated research objectives. RQ1 to RQ4 correspond to the first objective, while RQ5 to RQ7 are related to the second.

RQ1: How has the scientific production in this line of educational research evolved during the period 2015–2024?

RQ2: What research approach does the analysed articles follow?

RQ3: What dependent variables are the focus of attention for researchers in this line of inquiry?

RQ4: At which educational stages are the studies being conducted?

RQ5: What technical and pedagogical characteristics do the VGs used in STEM education have?

RQ6: Which key competencies does the use of VGs in STEM education contribute to?

RQ7: How do the characteristics of the VGs moderate the development of key competencies?

Phase 2. Scopus and Web of Science (Wos) were selected as the databases for this review, given their relevance and coverage in educational research. Five inclusion criteria were established, which align reciprocally with the exclusion criteria shown in **Figure 1**:

1. Records published within a decade, between 2015 and 2024.
2. Empirical article records published in journals.
3. Articles indexed in relevant categories or that include educational research (social sciences and education & educational research).
4. Articles published in English or Spanish.
5. Educational research aiming to test the effectiveness of one or more VGs for teaching and learning in one or more STEM fields.

Phase 3. A search strategy was defined and adapted for each of the databases used (**Table 1**), aiming to be as exhaustive as possible. The searches were conducted in the second half of March 2024.

Phase 4. The identification, screening, and inclusion processes were carried during the first half of April 2024 and is illustrated in **Figure 1**. In this regard, it is important to note that:

(1) inclusion criteria 1 to 4 were automated using the tools available in the databases,

(2) in the first screening, inclusion criterion 5 was applied, after the sequential execution of the previous four, based on the reading of the title and abstract of the publications, and

(3) the eligibility of the 57 articles was assessed through a full reading.

Phase 5. The management of data from those publications assessed for eligibility was performed using Microsoft Excel.

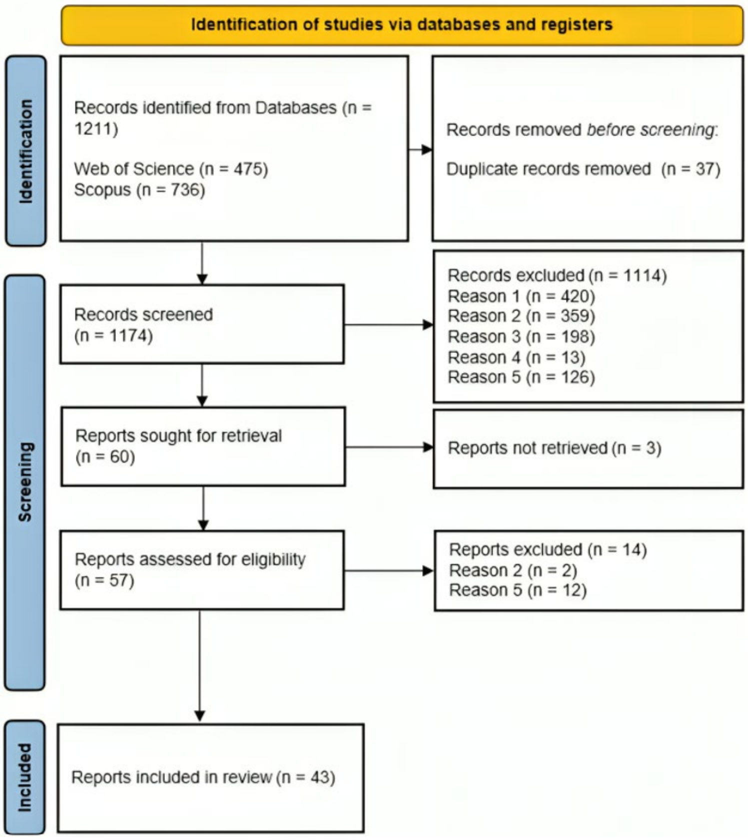

Figure 1. Flowchart illustrating the review process according to PRISMA 2020 (the authors' own elaboration)

Table 1. Search strategies used

Database	Equation
Scopus	TITLE-ABS-KEY(videogame or video-game or "video game") AND TITLE-ABS-KEY("STEM education" OR "science education" OR "physic* education" OR "chemi* education" or "bio* education" or "geo* education" or "mathematic* education" OR "engineering education" OR "technology* education" or "STEM learning" OR "science learning" OR "physic* learning" OR "chemi* learning" or "bio* learning" or "geo* learning" OR "mathematic* learning" OR "engineering learning" OR "technology* learning" or "STEM teaching" OR "science teaching" OR "physic* teaching" OR "chemi* teaching" or "bio* teaching" or "geo* teaching" OR "mathematic* teaching" OR "engineering teaching" OR "technology* teaching")
WoS	TS = (videogame or video-game or "video game") AND TS = ("STEM education" OR "science education" OR "physic* education" OR "chemi* education" or "bio* education" or "geo* education" or "mathematic* education" OR "engineering education" OR "technology* education" or "STEM learning" OR "science learning" OR "physic* learning" OR "chemi* learning" or "bio* learning" or "geo* learning" OR "mathematic* learning" OR "engineering learning" OR "technology* learning" or "STEM teaching" OR "science teaching " OR "physic* teaching" OR "chemi* teaching" or "bio* teaching" or "geo* teaching" OR "mathematic* teaching" OR "engineering teaching" OR "technology* teaching")

Phase 6. The coding and analysis of the articles included in the review were guided by a protocol previously defined by the authors. This protocol established 13 units of analysis, outlining the procedures to follow in the analysis and the way to code the data in the Excel table created specifically for this review. Finally, the data were exported to SPSS v.25 for analysis through cross-tabulations, applying Chi-square tests and Cramer's V to answer RQ7.

RESULTS AND DISCUSSION

58 VGs were identified across the 43 articles included in the review. These have been numbered to illustrate the results obtained and are referenced in the following document: https://doi.org/10.5281/zenodo.15034157

The results obtained are presented and discussed below, based on the RQs.

RQ1: Evolution of Scientific Production Between 2015–2024

Figure 2 shows the evolution of scientific production during the period 2015–2023, excluding 2024 (n = 1) as it was not complete when this review was conducted.

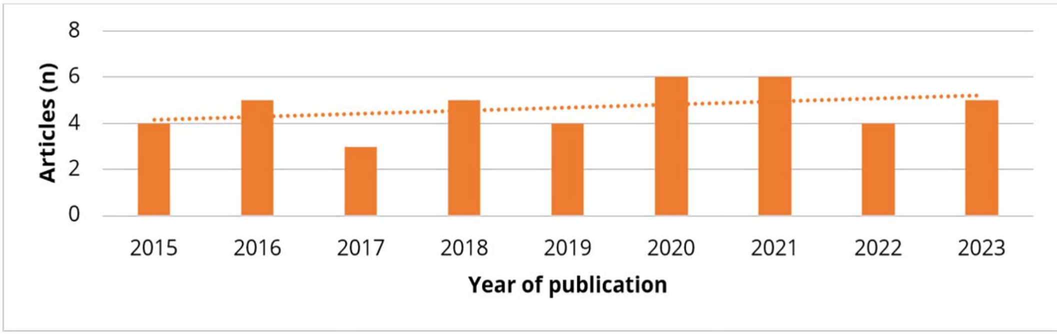

Figure 2. Graphical representation of scientific production between 2015 and 2023 (the authors' own elaboration)

The educational research line focused on the design and/or validation of VGs for STEM education shows stable scientific production during the analysed period, as evidenced by the trend line with a figure of between four and five empirical articles per year. A peak in production is observed between 2020 and 2021. This increase in scientific production could be related to the generalisation of DGBL, as this educational methodology has proven effective in both face-to-face and virtual environments, gaining particular relevance since the COVID-19 pandemic (López-Fernández et al., 2023; Udeozor et al., 2023).

RQ2: Approach of the Research

The research paradigm in which each study included in this review falls within was determined according to Kivunja and Kuyini (2017). **Figure 3** presents the distribution of the analysed studies according to the research paradigm in which they are framed.

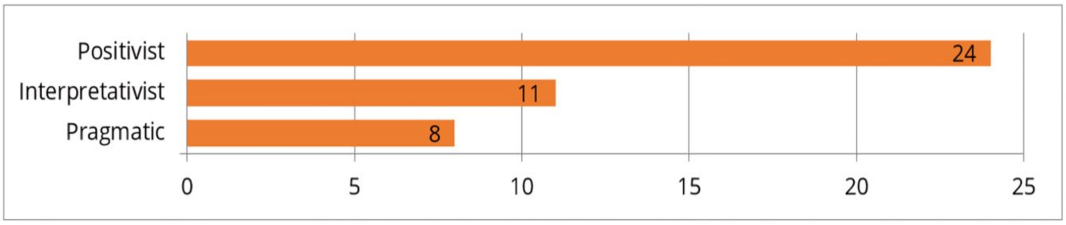

Figure 3. Classification of studies according to the research paradigm they adopt (the authors' own elaboration)

55.8% (n = 24) of the analysed articles fit within a positivist paradigm, which is considered the most suitable for their research. This indicates a preference for quantitative methodologies that allow for the evaluation of the nature of a phenomenon. These studies employ quasi-experimental and pre-experimental designs, generally with pre and post-test measurements. On the other hand, 25.6% (n = 11) of the studies are based on the interpretive paradigm, whose focus seeks to understand the experiences and perceptions of the participants. All of these apply research designs tailored to case studies. Finally, 18.6% (n = 8) of the articles adopt the pragmatic paradigm, which integrates both quantitative and qualitative approaches through a mixed methodology, to gain a more comprehensive view of the studied phenomenon and adopt research models based on design. These findings align with those of other reviews, where the positivist research approach and experimental designs predominated (Connolly et al., 2012; Chen et al., 2022; Pan et al., 2022).

RQ3: Dependent Variables Studied

A simplification of the multidimensional framework by Connolly et al. (2012) was applied to classify the dependent variables in accordance with the dimensions of learning impacted by the VGs (**Figure 4**).

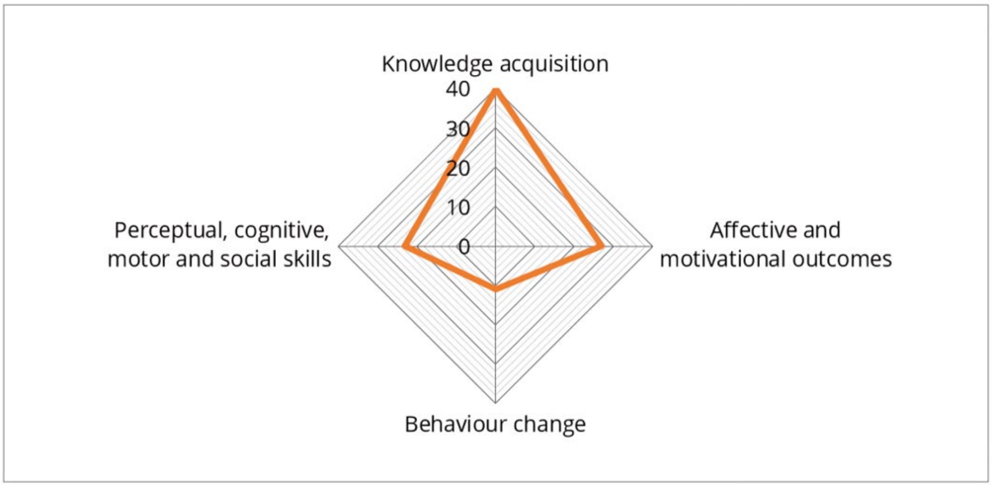

Figure 4. Classification of dependent variables based on the dimensions of learning (the authors' own elaboration)

Almost all of the studies (93%; n = 40) focused on evaluating knowledge acquisition mediated by VGs, highlighting their potential as educational tools to facilitate content learning. Additionally, a significant portion of the studies centred on the affective and motivational dimension (62.8%; n = 27), emphasising the ability of VGs to generate positive emotions, interest, and engagement. Furthermore, 53.4% of the studies examined the contribution of VGs to the development of skills (n = 23). In contrast, studies that focused on the mediation of VGs in behavioural changes were less frequent (25.6%; n = 11). This lower representation may reflect the difficulty VGs face in influencing sustainable behaviours or indicate the need for more specific design strategies to achieve such outcomes. Overall, the presence of studies covering multiple categories suggests that VGs can have diverse and complementary impacts, strengthening different dimensions of learning.

When compared with earlier research (2004–2009), these results indicate a shift in focus regarding the dependent variables under study. During that period, Connolly et al. (2012) identified that most studies concentrated on the affective dimension (34.1%) and the development of skills (30.2%). This trend shift is confirmed by the data provided by Hussein et al. (2019, 2022), who found that 73.9% of the articles published between 2006 and 2017 focused on evaluating scientific knowledge acquisition mediated by VGs, while 62.8% of those published between 2008 and 2019 focused on the acquisition of mathematical knowledge.

RQ4: Educational Stages in Which the Studies are Conducted

Figure 5 shows the distribution of the educational stages across the 43 studies. There are 44 stages in total, as one study was implemented in two educational stages.

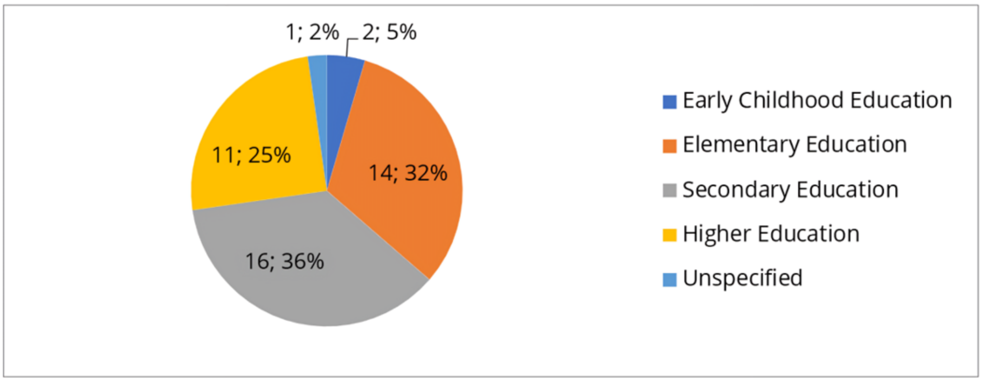

Figure 5. Distribution of studies by educational stages (the authors' own elaboration)

The results obtained differ from the findings of Chen et al. (2022), who found that many studies published between 1991 and 2020 primarily focused on primary education (40.3%), while higher education was significantly less represented (9.4%). This could be explained by the arrival of the centennial generation (born between 1995 and 2010) to university (since 2013) and the need to adapt teaching-learning processes to their characteristics and needs. Thus, students from this generation engage in intensive and extensive use of digital technologies in their daily lives (Giray, 2022).

Although trends vary, the general consensus seems to suggest that VGs are suitable for students at any educational level (Gui et al., 2023; Tsai & Tsai, 2020). Despite this, the limited presence of VGs in early childhood education could be consistent with concerns, particularly regarding the introduction of electronic devices (tablets, smartphones, etc.) and, more generally, educational technology for very young children (Su et al., 2024).

The analysis of the educational records reveals distinct patterns of interest in the studied period (**Figure 6**). During the years 2015–2019, there is a slight inclination towards secondary and higher education, while in the period 2020–2024, a trend shift towards primary education is observed. However, primary education maintains significant and consistent attention throughout the analysed period (2015–2024), while early childhood education has barely been addressed.

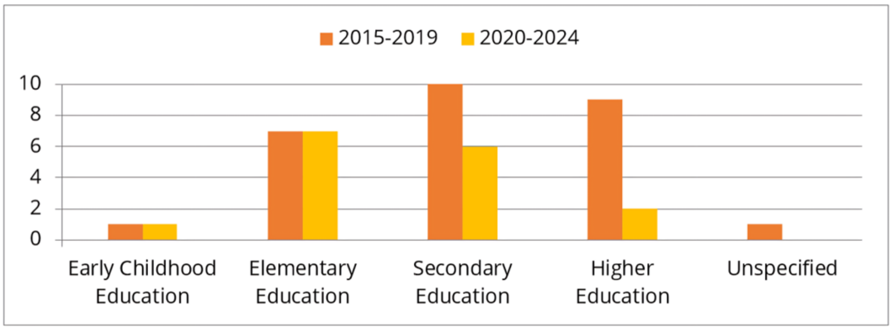

Figure 6. Distribution of studies by educational stages and periods (the authors' own elaboration)

RQ5: Technical and Pedagogical Characteristics of Video Games

The following presents the results based on the technical characteristics (type, mode of play, availability, and genre) and the pedagogical characteristics (STEM areas addressed, interdisciplinary, and cognitive demand) of the 58 VGs analysed.

Types, modes, and availability

74.1% (n = 43) of the VGs analysed are classified as serious games, meaning they were specifically designed for educational purposes. In contrast, 25.9% are commercial games (n = 15), whose main purpose is entertainment and, to some extent, economic profitability. While the latter are typically high-quality products that are appealing to the public, they align poorly with curricula. In contrast, serious games are intentionally designed with specific educational objectives, combining entertainment and learning in a purposeful way. This trend has become more pronounced in the period from 2021 to 2024, with a clear shift towards the production of VGs specifically tailored to address particular educational needs. In fact, during this time frame, only 14.2% of the VGs used in STEM education are commercial. These findings stand in stark contrast to those of Connolly et al. (2012) for the period between 2004 and 2009, where 52.7% of the VGs were commercial. This shift could indicate the challenges faced in the educational field in articulating innovation processes within classrooms.

Regarding the mode of play, there is a clear predominance of VGs designed for individual play, with a total of 51 (87.9%), compared to multiplayer mode (12.1%). This trend may be explained by the findings of Tsai and Tsai (2020), who demonstrated that individual VGs are more effective than multiplayer ones in scientific education.

Table 2 presents the availability of the analysed VGs. In the case of serious games, a significant proportion (44.1%) is not available, while a smaller percentage (9.3%) has restricted access. The high rate of unavailable serious games contrasts with the full availability of commercial VGs. This is mostly due to the obsolescence of the technology used to run the game (e.g., Flash) and, in other cases, the cost of maintaining and hosting the games online.

Table 2. Type of access to the video games

Availability	Serious games		Commercial games		Total	
	Frequency (N)	Percentage (%)	Frequency (N)	Percentage (%)	Frequency (N)	Percentage (%)
Open access	20	46.5	9	60.0	29	50.0
Restricted access	4	9.3	6	40.0	10	17.2
Not available	19	44.1	0	0.0	19	32.8

These findings suggest that distribution models and accessibility vary significantly between serious games and commercial VGs, with commercial games being more established in terms of access due to their economic sustainability (Udeozor et al., 2023). In this regard, platforms such as Itch.io (https://itch.io/) could provide a boost to improve accessibility to serious games, given their open and free nature.

Genre

To classify the genre of the VGs, the categories established by Choi et al. (2020) were used. The VGs were predominantly distributed between the strategy and action genres (69%; n = 40) (**Figure 7**).

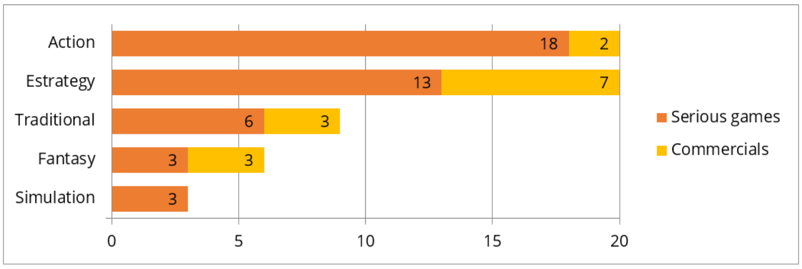

Figure 7. Distribution of video games by genre and type (the authors' own elaboration)

Serious games have been identified in all the VG genres covered by this analysis. However, no commercial VGs of the simulation genre have been recorded. This could be due to the fact that the simulation VGs analysed were aimed at reproducing actions (e.g., *Mission Biotech* aims to make players identify infectious agents) and/or phenomena (e.g., *Phet Electric Field Hockey Game* aims to make players play a hockey game under the physical 'rules' of the electric field) that are difficult to reproduce in everyday contexts and generally require pedagogical advice in their design to reconstruct them reliably without losing educational potential (Choi et al., 2020; Plass et al., 2020).

STEM areas and interdisciplinary

A large majority on the VGs analysed, 94.8%, focus on a single STEM discipline, while 5.2% (n = 3) present characteristics that align with integrated or interdisciplinary educational models (**Figure 8**). Among the latter we find the VGs: The *Radix Endeavor*, which combines Biology and Mathematics; *BacToMars*, which integrates Biology and Engineering; and *Mission Biotech*, which unites Biology and Technology. These results show that the design of interdisciplinary VGs remains low, as Chen et al. (2022) identified that only 3% of the studies published between 2011 and 2020, and consequently the digital and conventional games tested, addressed the scientific and mathematical areas in an interdisciplinary way. Furthermore, the fact that all interdisciplinary VGs were serious games could be indicative of a complex design process that must reconcile entertainment with learning from two or more STEM disciplines.

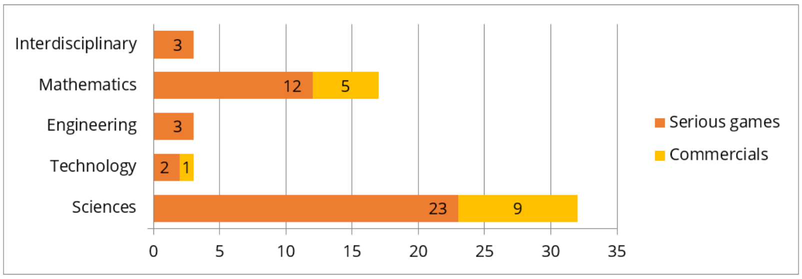

Figure 8. Distribution of video games by STEM areas and type (the authors' own elaboration)

Science education is currently the area contributing most actively to the development of DGBL, with 55.2% of the VGs (n = 32) focusing on this STEM area. Specifically, physics is the scientific discipline most worked on in the VGs (n = 14), dealing with both classical concepts (astrophysics, mechanics, kinematics, dynamics, Newton's laws, electromagnetism and electrodynamics) and advances in modern physics (special relativity). Followed by biology (n = 10), working from fundamental knowledge (anatomy, cellular functions, evolution and genetics) to practical applications relevant to health and biological research (microbiology, bacteriology and virology); chemistry (n = 5) with VGs focusing on learning about chemical reactions, the atom, molecular structures and the periodic table; and geography (n = 3) with VGs focusing on natural disasters. In the field of mathematics education, 29.3% of the VGs analysed (n = 17) are aligned with this area, primarily focusing on number sense (n = 10) and, to a lesser extent, on stochastic sense (n = 4) and algebraic sense (n = 3). These results are very similar to those obtained by Chen et al. (2022), who found that 59% of VGs research published between 2011 and 2020 corresponded to science education, while 38.1% were aligned with mathematics. In addition, Byun and Joung (2018) also identified that students' number sense was the focus of VGs designed for mathematics education between 2005 and 2014. Technology and engineering education are represented in 10.4% (n = 6) of the VGs analysed. These are mainly aimed at higher education (n = 4) and address issues related to computational thinking (n = 4) and those specific to mechanical engineering (n = 1) or biotechnology (n = 1).

While serious games are present across all STEM domains, their use is especially prominent in engineering education, where commercial games remain rare. In this regard, Udeozor et al. (2023) point out that the use of commercial VGs in engineering represents a challenge, given the nature of knowledge in this discipline and the specificity of the teaching-learning processes.

Cognitive demand

This category, which refers to the mental actions and processes that players must carry out during their interaction with the GV, has been coded according to the revised Bloom's taxonomy (Anderson & Krathwohl, 2001). The six categories included in this classification are (from the lowest to the highest degree of cognitive demand): remembering, understanding, applying, analysing, evaluating and creating. **Figure 9** presents the classification of the VGs according to the maximum cognitive demand they required and the educational stage at which they were applied.

From **Figure 9** we can establish that:

- 39.6% (n = 23) of the VGs are oriented exclusively towards understanding content, including basic cognitive tasks such as recalling and recognizing information,
- 12.1% (n = 7) require users to apply knowledge,
- 13.8% (n = 8) require the user to analyse, decomposing information, identifying relationships between elements and understanding how they are interrelated,
- 25.9% (n = 15) require evaluation, encouraging the student to justify decisions, argue and judge situations, and
- 8.6% (n = 5) of the GVs allow the user to generate new ideas, apply own models or build structures or algorithms according to the user's knowledge, representing the highest cognitive level to achieve according to the GVs analysed.
- In pre-school education, the cognitive requirements of the VGs are low, prioritising the assimilation of basic concepts and their application to everyday situations. Similarly, in primary education, VGs focus on the comprehension of content (40%; n = 6), although all cognitive demands are addressed.
- In contrast, in secondary education 77.3% (n = 17) of the VGs reach higher cognitive demands (analyse, evaluate and create), with the demand to evaluate (34.8%; n = 8) being predominant. These facts are logical and coherent with:
    (1) the cognitive development of secondary school students compared to primary school and pre-school students; and

(2) the objectives of compulsory basic education, which is aimed at the formation of a critical citizenry capable of actively participating in the resolution of current socio-environmental problems (Santamaría-Cárdaba et al., 2021).

- Interestingly, in higher education, the VGs used prioritise content comprehension (72.2%; n = 14) over the rest of the cognitive demands. This could be interpreted as an attempt on the part of university teaching to attend to the cognitive, affective and behavioural characteristics of the centennial generation (Giray, 2022), which would indicate the 'shift of emphasis' towards learning in the processes of knowledge transmission mediated by digital technologies (UNESCO, 2024).

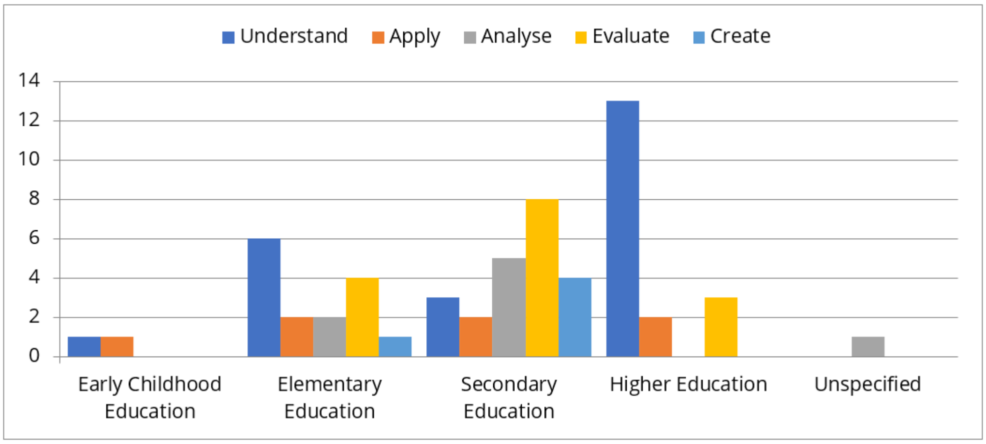

Figure 9. Maximum cognitive demand required by video games (the authors' own elaboration)

Taken together, these results suggest that VGs not only facilitate memorisation and acquisition of STEM concepts, but also enhance advanced cognitive skills such as critical thinking, creativity and problem solving (Chen et al., 2020; Gui et al., 2023; Huang et al., 2020). Along these lines, the National Research Council (2022) notes that DGBL plays a key role in strengthening cognitive and motor skills in STEM domains, as integrating various instructional support mechanisms effectively enhances them (Klopfer & Thompson, 2020).

RQ6: Key Competencies Promoted by the Video Games in STEM Areas

To identify the key competencies involved in the VGs analysed (**Table 3**), those established by the DeSeCo project (OECD, 2003) have been used.

The results indicate that VGs mainly contribute to the development of competencies in 'category 1–using tools interactively' and, more specifically, to competencies in 'category 2–interactive use of knowledge and information' and 'category 3–interactive use of technology'. This is due to the nature of these resources, as they enable learning in technology-mediated environments (Makokha, 2017). In contrast, the impact on competencies in 'category 2–interacting in heterogeneous groups' and 'category 3–acting autonomously' is very small. Thus, the fact that only seven (12.5%) of the VGs analysed were multiplayer would explain the low development of 'category 2–competencies. In this regard, Steinkuehler and Williams (2006) identified that VGs can constitute spaces for social interaction called 'third places', demonstrating that different genres of VGs are effective as third places for interaction between players. However, in light of the results obtained, we can affirm that single-player VGs also allow interaction with non-player characters that emulate collaborative actions, negotiation processes and shared decision-making. Moreover, only 8.6% (n = 5) of the analysed VGs reach the highest cognitive demand (create) could be related to the null development of competence 8 'form and lead life plans and personal projects' and 9 'defend and secure rights, interests, limits and needs'. However, 25.6% of the VGs analysed have evidenced ability to develop competence 7 'act within the context of the big picture', which would be closely related to the cognitive demand to evaluate which is one of the most worked on by VGs in STEM areas.

A notable example of a more comprehensive competency approach is *Virulent*. This is a serious multiplayer strategy game designed by the Games and Learning Society Research Centre at the University of Wisconsin-Madison for learning about the process of virus replication. In this VG, which contributes to the development

Table 3. Contribution of video games to the development of key competencies (OECD, 2003)

Competencies	Skill/capacity	Frequency (%)
Category 1. Using tools interactively		
1. Interactive use of language, symbols, and texts	Oral and written language skills in computing and mathematics.	21 (36.2)
2. Interactive use of knowledge and information	Recognising and determining what is not known: identifying, locating and accessing appropriate sources of information, assessing the quality, ownership and value of such information and its sources, and organising knowledge and information.	58 (100)
3. Interactive use of technology	Relate the possibilities that lie in technological tools to their own circumstances and goals and incorporate technology into common practices.	58 (100)
Category 2. Interacting in heterogeneous groups		
4. Relating well with others	Fostering emotional intelligence, respecting and appreciating the beliefs, cultures and histories of others, developing empathy, self-reflection, effective management of emotions, knowledge about oneself and others …	-
5. Cooperating and working as a team	Ability to present ideas and to listen to others' ideas, understanding of the dynamics of debate and following an agenda, building alliances, negotiating, taking decisions …	17 (29.3)
6. Managing and resolving conflicts	Analyse the elements and interests at stake, the origins of the conflict and the reasoning of all parties, recognising that there are different possible positions; identify areas of agreement and disagreement; contextualise the problem and prioritise needs.	-
Category 3. Acting autonomously		
7. Acting in the context of the big landscape	Understanding of patterns, knowledge of the system in which they exist (structures, culture, practices, rules, roles and social norms); identification of consequences of their actions and reflection on them.	15 (25.9)
8. Forming and leading life plans and personal projects	Defining project and goals, identifying, balancing and evaluating resources, prioritising goals, learning from past actions and projecting future results, and monitoring progress and making necessary adjustments.	-
9. Defending and securing rights, interests, limits, and needs	Understanding own and collective interests, knowing the rules and principles on which to base a case, constructing arguments for one's rights and needs to be recognised, suggesting alternative arrangements or solutions.	-

of competencies in all three categories, players collaborate to control different cells (e.g., white blood cells) and organic molecules (e.g., antibodies) to prevent, in the first instance, viruses from entering target cells and, ultimately, to prevent their replication. So much so that DGBL provides virtual environments in which students can experiment with phenomena that would be difficult to reproduce with traditional teaching resources (Talan et al., 2020), offering the opportunity to tackle authentic problems (Strawhacker et al., 2018).

RQ7: Implications of the Video Games' Characteristics for Competence Development

All VGs, regardless of their technical and pedagogical characteristics, were aligned with practices from competencies 2 'interactive use of knowledge and information' and 3 'interactive use of technology' of the DeSeCo framework (OECD, 2003). However, according to the results obtained, it seems that the technical characteristics of the VGs condition their contribution to competence development to a greater extent than the pedagogical aspects analysed:

- Type of VG. Serious games seem to be related to a higher number of skills than commercial games. Thus, a significant association between these two variables has been identified ($\chi2 = 3.182$; $p < .05$), although of low degree (Cramer's V = 0.234; $p < .05$).
- Game mode. Only 24% of single-player VGs contributed to the development of competency 5 'cooperate and work as a team', compared to 57% of multiplayer VGs. This reflects a significant relationship between game mode and this competency ($\chi2 = 3.481$; $p < .05$), albeit of low degree (Cramer's V = 0.245; $p < .05$).

- Genre of the VG. It has been identified that 60% of the action VGs, as well as 44% of those classified as traditional, showed educational elements aligned with competence 1 'Interactive use of language, symbols and texts'. So much so that there seems to be an association between the genre of the VGs and this competence ($\chi2 = 12.311$; $p < .05$), being of moderate degree (Cramer's V = 0.461; $p < .05$). The same is true for competency 7 'act within the context of the big picture', identifying a significant relationship with the genre of the VGs ($\chi2 = 8.105$; $p < .05$) of moderate degree (Cramer's V = 0.374; $p < .05$). In this case, 67% of the simulation VGs and 50% of those categorised as fantasy offer didactic aspects aligned with competence 7.
- Cognitive demand. A relationship was found between the maximum cognitive demand of the VGs and competence development (**Figure 10**), being moderate (Cramer's V = 0.434; $p < .05$).
- Disciplinary integration, as well as the STEM contents worked on in those monodisciplinary VGs, did not show a significant relationship with the competencies that could be promoted by the VGs.

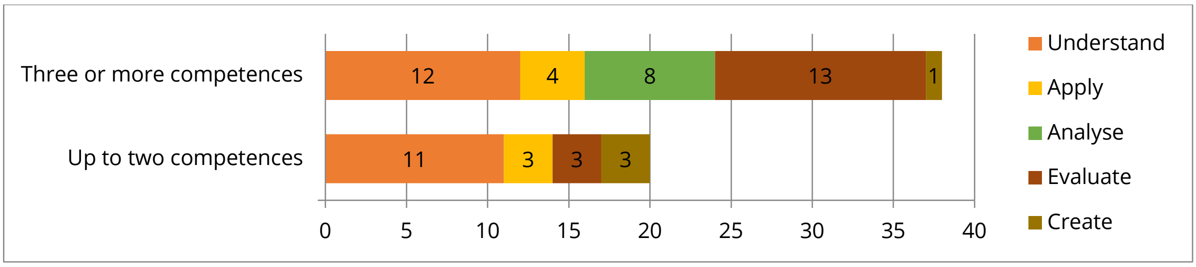

Figure 10. Relationship between the cognitive demand of the video game and competence development ($\chi^2 = 10.900$; $p < .05$) (the authors' own elaboration)

Thus, relationships have been found between the technical and pedagogical characteristics of the VGs and their potential to develop key competencies. Some of these relationships may be to be expected, such as the type of the VGS (since serious games are designed ad hoc for user learning, we would expect them to have a greater potential for competence development), the game mode (multiplayer VGs favour the competence of cooperating and working in teams) or the cognitive demand (if a VGs develops more competencies, it is coherent that it also implies more complex cognitive demands). Other relationships may be more surprising, or at least complex, such as the association with VG genre, where it is clear that all genres are useful for learning, although some genres seem to have a greater potential with respect to certain key competencies. And finally, it is also striking that the GVs in each STEM domain seem to contribute equally to the development of key competencies, and no hierarchies can be established between them.

At this point, it seems that DGBL is an effective methodology for developing key competencies in students, as demonstrated by different empirical studies (e.g., López-Fernández et al., 2023; Strawhacker et al., 2018) and evidenced in different meta-analyses (e.g., Byun & Joung; 2018; Gui et al., 2023; Wang et al., 2022). This is a fact that both students and teachers are aware of, as revealed by Martínez (2019) from his interpretative study supported by semi-structured interviews. However, in the light of the results obtained, it seems necessary to pay due attention to the technical aspects of the VG to be implemented to teach one or more STEM disciplines, as these could predefine the students' competence development.

CONCLUSIONS

A systematic review study was carried out

(1) to review the state of the art regarding the use of VGs in STEM education and

(2) to analyse the characteristics of the VGs used in STEM education and their implications for students' competency development.

Regarding the first objective, we can conclude that the line of research focused on the design of VGs for the teaching-learning of STEM subjects is consolidated, contributing between four and five empirical articles per year in the period 2015–2024. However, it would be advisable to intensify research in this educational line in order to study the risks involved in the use of VGs in education and, within this, in STEM-specific didactics.

The research included in this review mostly conforms to the positivist paradigm and follows quasi-experimental designs. Thus, studies that adopt a pragmatic view of educational research and apply mixed designs are needed to guide the process of designing VGs. Studies have mainly focused on analysing the ability of VGs to improve students' understanding of STEM knowledge, neglecting the impact of VGs in promoting certain behaviours. Therefore, the evaluation of the ability of VGs to promote desirable socio-environmental behaviours within the framework of STEM areas and the sustainable development goals is identified as a priority. Most research has been carried out in primary and secondary education, with early childhood education being relegated to second place. However, in the period 2015–2019, research in higher education intensified. This seems to be due to the consolidation of e-learning and the adaptation of university teaching to the characteristics of the new generations. Consequently, specific STEM didactics need to address the educational use of VGs and their risks in early childhood education.

Concerning the second objective, we can conclude that the type of technical and didactic profile of the VGs, according to the results obtained, corresponds to: a single-player serious game published in open access, whose genre is action or strategy, aimed at the teaching-learning of a STEM discipline and which caters, as a whole, to all levels of cognitive complexity. The VGs seem to be mainly linked to the development of competencies related to the interactive use of knowledge and technology, although they also show characteristics that align them with competencies associated with the interactive use of language, symbols and texts, as well as those related to the autonomous action of students in the framework of problem solving. The technical characteristics of the GVs seem to condition, to a greater extent than the pedagogical aspects analysed, their contribution to the students' competence development. Thus, serious games show a greater number of competencies than commercial games; multiplayer VGs show more opportunities to develop competencies related to social interaction; action and traditional VGs are the best for the development of competencies related to the interactive use of language, symbols and texts; while simulation and fantasy VGs are the best options for developing competencies related to the autonomous resolution of complex problems in concrete situations.

Author contributions: ARS: validation, data curation, formal analysis, writing – original draft; **AB:** validation, methodology, writing – review & editing; **FJC-R:** data curation, writing – review & editing, conceptualization; **DA:** formal analysis, writing – original draft, methodology, conceptualization, funding acquisition, supervision. All authors approved the final version of the article.

Funding: This article is part of the R&D&I project C-SEJ-055-UGR23 (STEMgame) funded by Consejería de Universidad, Investigación e Innovación and by European Union under ERDF Andalusia Program 2021-2027.

Ethics declaration: This study is based solely on a systematic review of previously published literature. As no data were collected from human participants and no interventions were conducted, ethical approval was not required.

Declaration of interest: The authors declared no competing interest.

Data availability: The data collected is available at: https://doi.org/10.5281/zenodo.15034172. The review protocol is available at: https://doi.org/10.5281/zenodo.15034127. The bibliographical references of the studies included in the review are available at: https://doi.org/10.5281/zenodo.15034157.

REFERENCES

Anderson, L. W., & Krathwohl, D. (2001). *A taxonomy for learning, teaching and assessing: A revision of Bloom's taxonomy of educational objectives*. Longman.

Brown, C. L., Comunale, M. A., Wigdahl, B., & Urdaneta-Hartmann, S. (2018). Current climate for digital game-based learning of science in further and higher education. *FEMS Microbiology Letters, 365*(21), Article fny237. https://doi.org/10.1093/femsle/fny237

Buntins, K., Bond, M., Bedenlier, S., Kerres, M., & Zawacki-Richter, O. (2019). *Systematic reviews in educational research: Methodology, perspectives and application*. Springer.

Byun, J., & Joung, E. (2018). Digital game-based learning for K-12 mathematics education: A meta-analysis. *School Science and Mathematics, 118*(3–4), 113–126. https://doi.org/10.1111/ssm.12271

Chen, C.-H., Shih, C.-C., & Law, V. (2020). The effects of competition in digital game-based learning (DGBL): A meta-analysis. *Educational Technology Research and Development, 68*(4), 1855–1873. https://doi.org/10.1007/s11423-020-09794-1

Chen, P.-Y., Hwang, G.-J., Yeh, S.-Y., Chen, Y.-T., Chen, T.-W., & Chien, C.-H. (2022). Three decades of game-based learning in science and mathematics education: An integrated bibliometric analysis and systematic review. *Journal of Computer Education, 9*, 455–476. https://doi.org/10.1007/s40692-021-00210-y

Choi, E., Shin, S. H., Ryu, J. K., Jung, K. I., Kim, S. Y., & Park, M. H. (2020). Commercial video games and cognitive functions: Video game genres and modulating factors of cognitive enhancement. *Behavioral Brain Function, 16*, Article 2. https://doi.org/10.1186/s12993-020-0165-z

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers & Education, 59*(2), 661–686. https://doi.org/10.1016/j.compedu.2012.03.004

Dou, L. (2019). *A cold thinking on the development of STEM education* [Paper presentation]. The International Joint Conference on Information, Media and Engineering. https://doi.org/10.1109/IJCIME49369.2019.00027

Giray, L. (2022). Meet the centennials: Understanding the generation Z students. *International Journal of Sociologies and Anthropologies Science Reviews, 2*(4), 9–18.

Grivokostopoulou, F., Kovas, K., & Perikos, I. (2020). The effectiveness of embodied pedagogical agents and their impact on students learning in virtual worlds. *Applied Sciences, 10*(5), Article 1739. https://doi.org/10.3390/app10051739

Gui, Y., Cai, Z., Yang, Y., Kong, L., Fan, X., & Tai, R. H. (2023). Effectiveness of digital educational game and game design in STEM learning: A meta-analytic review. *International Journal of STEM Education, 10*, Article 36. https://doi.org/10.1186/s40594-023-00424-9

Huang, S.-Y., Kuo, Y.-H., & Chen, H.-C. (2020). Applying digital escape rooms infused with science teaching in elementary school: Learning performance, learning motivation, and problem-solving ability. *Thinking Skills and Creativity, 37*, Article 100681. https://doi.org/10.1016/j.tsc.2020.100681

Hussein, M. H., Ow, S. H., Cheong, L. S., Thong, M. K., & Ebrahim, N. A. (2019). Effects of digital game-based learning on elementary science learning: A systematic review. *IEEE Access, 7*, 62465–62478. https://doi.org/10.1109/ACCESS.2019.2916324

Hussein, M. H., Ow, S. H., Elaish, M. M., & Jensen, E. (2022) Digital game-based learning in K-12 mathematics education: A systematic literature review. *Education and Information Technologies, 27*, 2859–2891. https://doi.org/10.1007/s10639-021-10721-x

Johnson, C. C., Moore, T. J., Utley, J., Breiner, J., Burton, S. R., Peters-Burton, E. E., & Walton, J. B. (2021). The STEM road map for grades 6–8. In C. C. Johnson, E. E. Peters-Burton, & T. J. Moore (Eds.), *STEM road map 2.0: A framework for integrated STEM education in the innovation age* (pp. 96–123). Routledge. https://doi.org/10.4324/9781003034902

Kayan-Fadlelmula, F., Sellami, A., Abdelkader, N., & Umer, S. (2022). A systematic review of STEM education research in the GCC countries: Trends, gaps and barriers. *International Journal of STEM Education, 9*, Article 2. https://doi.org/10.1186/s40594-021-00319-7

Kivunja, C., & Kuyini, A. B. (2017). Understanding and applying research paradigms in educational context. *International Journal of Higher Education, 6*(5), 26–41. https://doi.org/10.5430/ijhe.v6n5p26

Klopfer, E., & Thompson, M. (2020). Game-based learning in science, technology, engineering, and mathematics. In J. L. Plass, R. E. Mayer, & B. D. Homer (Eds.), *Handbook of game-based learning* (p. 387). MIT Press.

Kukulska-Hulme, A., Wise, A. F., Coughlan, T., Biswas, G., Bossu, C., Burriss, S. K., Charitonos, K., Crossley, S. A., Enyedy, N., Ferguson, R., FitzGerald, E., Gaved, M., Herodotou, C., Hundley, M., McTamaney, C., Molvig, O., Pendergrass, E., Ramey, L., Sargent, … Whitelock, D. (2024). *Innovating Pedagogy 2024: Open University Innovation Report 12*. The Open University.

Lameras, P., Arnab, S., Dunwell, I., Stewart, C., Clarke, S., & Petridis, P. (2017). Essential features of serious games design in higher education: Linking learning attributes to game mechanics. *British Journal of Educational Technology, 48*(4), 972–994. https://doi.org/10.1111/bjet.12467

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press. https://doi.org/10.1017/CBO9780511815355

López-Fernández, D., Gordillo, A., Pérez, J., & Tovar, E. (2023). Learning and motivational impact of game-based learning: Comparing face-to-face and online formats on computer science education. *IEEE Transactions on Education, 66*(4), 360–368. https://doi.org/10.1109/te.2023.3241099

Makokha, J. (2017). Emerging technologies and science teaching. In K. S. Taber, & B. Akpan (Eds.), *Science education. An international course companion* (pp. 369–383). Brill. https://doi.org/10.1007/978-94-6300-749-8_27

Martínez, J. (2019). Percepciones de estudiantes y profesores acerca de las competencias que desarrollan los videojuegos [Students' and teachers' perceptions of the skills developed by video games]. *Pensamiento Educativo, 56*(2). https://doi.org/10.7764/PEL.56.2.2019.3

Martínez-Garza, M., Clark, D., & Nelson, B. C. (2013). Digital games and the US National Research Council's science proficiency goals. *Studies in Science Education, 49*(2), 170–208. https://doi.org/10.1080/03057267.2013.839372

Mayer, R. E. (2014). *Computer games for learning: An evidence-based approach*. MIT Press. https://doi.org/10.7551/mitpress/9427.001.0001

National Research Council. (2022). *Science and engineering in preschool through elementary grades: The brilliance of children and the strengths of educators*. National Academies Press.

OECD. (2003). *The definition and selection of key competencies. Executive summary*. OECD. https://one.oecd.org/document/EDU/EDPC/ECEC/RD(2010)26/en/pdf

Ortiz-Revilla, J., Greca, I. M., & Adúriz-Bravo, A. (2021). Conceptualización de las competencias: Revisión sistemática de su investigación en educación primaria [Conceptualization of competencies: A systematic review of research in primary education]. *Profesorado, Revista de Currículum y Formación del Profesorado, 25*(1), 223–250. https://doi.org/10.30827/profesorado.v25i1.8304

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hrobjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., … Alonso-Fernández, S. (2021). Declaración PRISMA 2020: Una guía actualizada para la publicación de revisiones sistemáticas [PRISMA 2020 statement: An updated guide to publishing systematic reviews]. *Revista Española de Cardiología, 74*(9), 790–799. https://doi.org/10.1016/j.recesp.2021.06.016

Pan, Y., Ke, F., & Xu, X. (2022). A systematic review of the role of learning games in fostering mathematics education in K-12 settings. *Educational Research Review, 36*, Article 100448. https://doi.org/10.1016/j.edurev.2022.100448

Plass, J. L., Mayer, R. E., & Homer, B. D. (2020). *Handbook of game-based learning*. MIT Press.

Santamaría-Cárdaba, N., Martínez-Scott, S., & Vicente-Mariño, M. (2021). Discovering the way: Past, present and possible future lines of global citisenship education. *Globalisation, Societies and Education, 19*(5), 687–695. https://doi.org/10.1080/14767724.2021.1878012

Steinkuehler, C., & Williams, D. (2006). Where everybody know your (screen) name: Online games as "third places". *Journal of Computer-Mediated Communication, 11*(4), 885–909. https://doi.org/10.1111/j.1083-6101.2006.00300.x

Strawhacker, A., Sullivan, A., Verish, C., Bers, M. U., & Shaer, O. (2018). Enhancing children's interest and knowledge in bioengineering through an interactive videogame. *Journal of Information Technology Education: Innovations in Practice, 17*, 55–81. https://doi.org/10.28945/3976

Su, J., Zhong, Y., & Chen, X. (2024). Technology education in early childhood education: A systematic review. *Interactive Learning Environments, 32*(6), 2848–2861. https://doi.org/10.1080/10494820.2022.2160470

Talan, T., Dogan, Y., & Batdi, V. (2020). Efficiency of digital and non-digital educational games: A comparative meta-analysis and a meta-thematic analysis. *Journal of Research on Technology in Education, 52*(4), 474–514. https://doi.org/10.1080/15391523.2020.1743798

Tsai, Y.-L & Tsai, C.-C. (2020). A meta-analysis of research on digital game-based science learning. *Journal of Computer Assisted Learning, 36*(3), 280–294. https://doi.org/10.1111/jcal.12430

Udeozor, C. Toyoda, R., Russo Abegão, F., & Glassey, J. (2023) Digital games in engineering education: Systematic review and future trends. *European Journal of Engineering Education, 48*(2), 321–339. https://doi.org/10.1080/03043797.2022.2093168

UNESCO. (2024). *Global education monitoring report 2023: Technology in education: A tool on whose terms?* UNESCO. https://doi.org/10.54676/NEDS2300

Valle, J., & Manso, J. (2013). Key competences as a trend in the supranational educational policies of the European Union. *Revista de Educación*,12–33. https://doi.org/10.4438/1988-592X-RE-2013-EXT-255

Wahono, B., Lin, P.-L., & Chang, C.-Y. (2020). Evidence of STEM enactment effectiveness in Asian student learning outcomes. *International Journal of STEM Education, 7*, Article 36. https://doi.org/10.1186/s40594-020-00236-1

Wang, L. H., Chen, B., Hwang, G. J., Guan, J. Q., & Wang, Y. Q. (2022). Effects of digital game-based STEM education on students' learning achievement: A meta-analysis. *International Journal of STEM Education, 9*(26), 2–13. https://doi.org/10.1186/s40594-022-00344-0