Impact of Game-Based Learning on Engineering Education: A Systematic Review

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Abstract
The evolving landscape of Engineering Education (EE) necessitates innovative pedagogical strategies to meet industry needs. Game-Based Learning (GBL) integrates gaming elements into educational contexts, enhancing interactivity and engagement. However, the effectiveness of GBL across various academic levels and disciplines remains underexplored. This systematic literature review aims to comprehensively analyze the use of GBL in EE, focusing on its application across various engineering fields and educational levels, the goals driving its implementation, the design features of GBL tools, and their educational outcomes. Utilizing IEEE Xplore for literature search and Rayyan AI for systematic review management, 22 studies were included after rigorous screening. Results indicate GBL's predominant use at the undergraduate level, especially in fields linked to digital technologies. Key goals for GBL include enhancing motivation, supporting skills development, and improving engagement and practical skills. Design features like interactive gameplay, feedback mechanisms, and 3D environments were identified. GBL significantly improves student engagement, motivation, knowledge acquisition, learning experiences, and practical skills development, typically investigated using mixed-methods research designs. This review highlights GBL's potential in the field of EE, offering insights into its application, design features, and benefits, and guiding future research and implementation strategies.

Keywords: Game-Based Learning, Engineering Education, Educational Outcomes, Interactive Learning, Digital Technology.

Introduction

The rapidly evolving landscape of Engineering Education (EE) demands innovative pedagogical strategies that effectively bridge the gap between current industry requirements and traditional educational outcomes. Industries increasingly require graduates who possess technical proficiency along with skills in collaboration, leadership, and problem-solving (McGunagle & Zizka, 2020). This has highlighted the limitations of conventional educational methods and spurred interest in alternative approaches like GBL when training engineering students.

GBL involves the integration of games to support teaching and learning objectives that infuses the engaging elements of gaming into educational environments, aiming to enrich learning experiences through increased interactivity, competition, and simulation (Gee, 2003; Pivec, 2007). Recognized for its potential to significantly enhance student engagement and facilitate the acquisition of complex competencies (Garcia et al., 2020; Udeozor et al., 2022), GBL represents a promising approach to meet the dynamic demands of contemporary EE.

This review gains importance in the context of the Fourth Industrial Revolution (IR4.0) transitioning into the Fifth Industrial Revolution (IR5.0), characterized by significant technological advancements and a shift toward more personalized, collaborative, and sustainable practices. Additionally, the during and post-COVID-19 era has accelerated the adoption of digital technologies and remote learning modalities, presenting both challenges and opportunities for the integration of GBL into engineering curricula (Rassudov & Korunets, 2020).

Despite its potential, the application of GBL in EE needs thorough examination to comprehend its effectiveness across various academic levels and disciplines. Previous reviews often focus on specific fields like software and computer engineering and do not explore the broader applications across diverse fields such as mechanical, electrical, and civil engineering, nor do they sufficiently consider different

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academic levels (Alanne, 2015; Garcia et al., 2020; Despeisse, 2018). Besides that, a review by Udeozor et al. (2022) while they do address GBL in EE, however, is limitedly to digital games utilization.

Moreover, with the increasing interest in gaming among young adults, it is critical to evaluate how GBL can be optimized to enhance educational outcomes. For instance, in Malaysia, gaming exhibits a substantial overall penetration rate of 85%, reaching 100% among individuals aged 20 and below (Survey Report: Malaysian Gaming Industry 2023, Engagement Lab). Hence, this review aims to provide an updated, comprehensive analysis of both digital and non-digital GBL utilization, their integration into engineering curricula, and assessing their impact on educational outcomes through the following research questions:

RQ1: *How do different academic levels and engineering fields shape the use of GBL?*

RQ2: *What goals lead to using GBL in EE, and how do these goals affect the choice of games and platforms?*

RQ3: *What are the main design features and standards for developing GBL tools, and how are these tools used in engineering courses?*

RQ4: *What educational outcomes does GBL bring to EE, and how they are typically investigated?*

Methods

. Our literature search was carried out across IEEE Xplore database as previous related reviews indicate the most common and highest studies pertinent to GBL in EE are in the mentioned database (Alanne, 2015; Despeisse, 2018; Garcia et al., 2020; Udeozor et al., 2022). We utilized a combination of Boolean operators, wildcards, and specific search terms related to GBL and EE. The search string: *("game-based learning" OR "digital game-based learning" OR "GBL" OR "DGBL" OR "serious game*" OR "educational game*") AND ("engineering education" OR "STEM education")*, is tailored to IEEE Xplore database to maximize the retrieval of relevant studies.

A literature matrix table was constructed to systematically record and extract relevant information such as objectives, methodologies, and findings from the selected studies. Following this, we primarily utilized thematic analysis to analyze and synthesize the extracted data, complemented by minor quantitative statistical analysis. This approach allowed us to identify common themes, patterns, and relationships across the studies. Through collaborative efforts, all three authors contributed to the qualitative synthesis, ensuring a comprehensive integration of data and deriving meaningful insights.

Our systematic literature review adheres to strict inclusion criteria to ensure the relevance and quality of the studies analyzed, as follows:

1. **Specific to EE:** Only studies explicitly focusing on engineering disciplines at either the undergraduate or graduate level were included. This encompasses studies on general engineering as well as specific branches such as mechanical, electrical, civil, and chemical engineering.
2. **Use of GBL:** Studies included were those that specifically investigated the implementation and outcomes of GBL. Covered methodologies included simulations, virtual reality, serious games, board games, and both digital and non-digital games designed for educational purposes.
3. **Reported Outcomes:** The review focused on empirical studies that involved conducting original research based on direct or indirect observations or experiences, aimed at generating new data.
4. **Publication Date:** Only studies published from January 2019 to April 2024 were considered to capture the most current insights and trends in the field.
5. **Language:** The search was limited to studies published in English to facilitate thorough review and analysis.
6. **Document Type:** The review was confined to peer-reviewed journal and conference papers to ensure the quality and scholarly rigor of the sources.
7. **Methodological Approach:** The studies included adopted quantitative, qualitative, and mixed-methods research designs.

Rayyan AI Application to Aid Selection Process

The selection process involved a preliminary screening of titles and abstracts followed by a full-text review, utilizing Rayyan AI (https://www.rayyan.ai/) for systematic review management. Rayyan is a collaborative web-based platform designed to facilitate the systematic literature review process. It aids study selection by allowing for references importation, offers tools for manual with suggested deduplication, and enables blind reviews to minimize bias. This feature is especially beneficial in efficiently managing the large volumes of data typically involved in SLRs, ensuring a rigorous and systematic assessment of literature and is also time saving (Ouzzani et al., 2016). Therefore, by employing Rayyan, independent reviews by each author were done, and for any disagreements were resolved in discussion to reach consensus.

Figure 1. Word cloud generated by Rayyan AI

Figure 1 shows a feature of Rayyan AI that showing the most common topics within reviewed articles. Initially, we created a new review in Rayyan and imported references from various databases. The platform's automated and manual deduplication tools ensured a clean dataset. Reviewers, invited via email, used the blind review feature to independently screen articles. Decisions were color-coded for clarity: red for exclusions, green for inclusions, and white for articles marked as 'maybe', as illustrated in Figure 2 below.

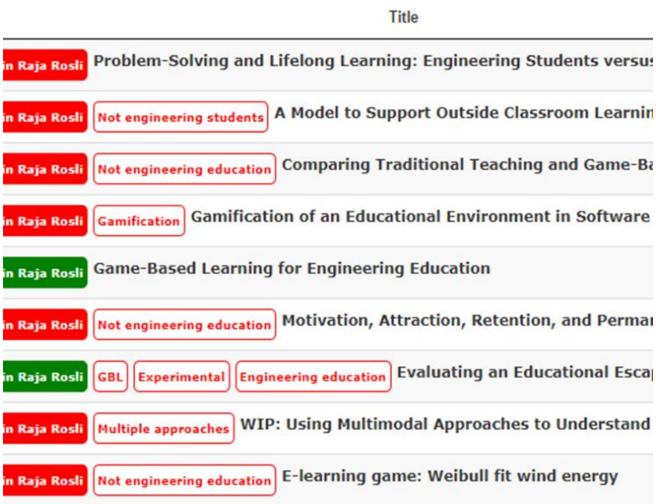

Figure 2. Rayyan AI interface showing article screening decisions

Reviewers also added specific labels and exclusion reasons to each reference as shown in Figure 3. After the initial screening, we resolved conflicts through consensus discussions. For the full-text review, included references were copied into a new review where full texts were uploaded and mapped for detailed evaluation. Upon completion, Rayyan facilitated the export of included references and provided a log of all review actions, ensuring transparency and reproducibility. Images illustrating the Rayyan AI interface and our process, highlighting the red, green, and white color indications, have been included to enhance clarity.

Figure 3. Exclusion reasons tracked in Rayyan AI

The search initially yielded 388 records. After automatic filtering, removing duplicates and screening titles and abstracts, 36 articles were reviewed in full text. Ultimately, only 22 studies met the rigorous inclusion criteria in this review. The selection process is detailed by adopting PRISMA flow diagram as shown in Figure 4, illustrating the narrowing from initial identification to final inclusion.

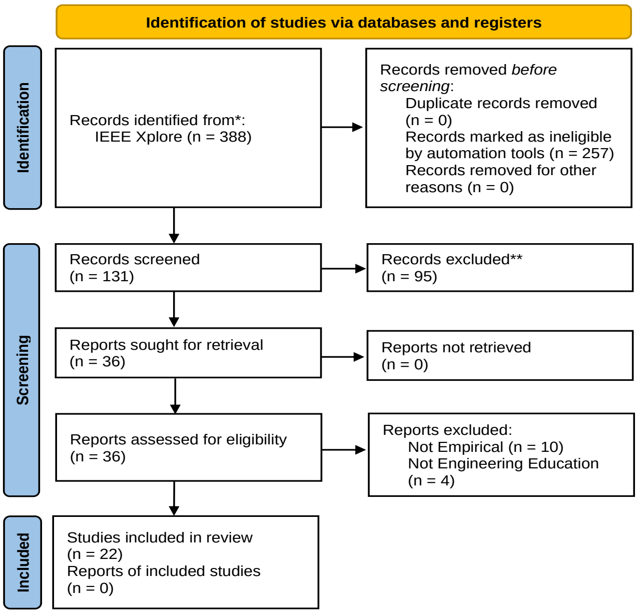

Figure 4. PRISMA 2020 flow diagram illustrating the process of study selection (Page et al. 2020)

Results

A. Influence of Academic Levels and Engineering Fields on the Use of Game-Based Learning

Figure 5 reveals that GBL is predominantly utilized at the undergraduate level across various engineering disciplines. Software Engineering stands out with the highest number of undergraduate studies (6), followed by Electrical and Computer Engineering (3). Studies such as Ivanova, Kozov & Zlatarov (2019) and Oren, Pedersen & Butler-Purry (2021) exemplify the integration of GBL into undergraduate courses, indicating a preference for interactive tools to enhance foundational education. The chart also shows that disciplines closely linked to digital technologies, such as Software and Electrical Engineering, frequently employ GBL. This reflects a trend where GBL is leveraged to align with the interactive and technological nature of these fields. Although fewer in number, some studies investigate GBL at the postgraduate level, as seen in fields like Software Engineering and Civil Engineering. This suggests that GBL is recognized for its value even in advanced educational stages, providing a versatile tool for enhancing learning outcomes. Overall, the distribution of GBL usage across undergraduate and postgraduate levels in various engineering fields highlights its adaptability and appeal in EE, demonstrating its effectiveness in both foundational and advanced educational contexts.

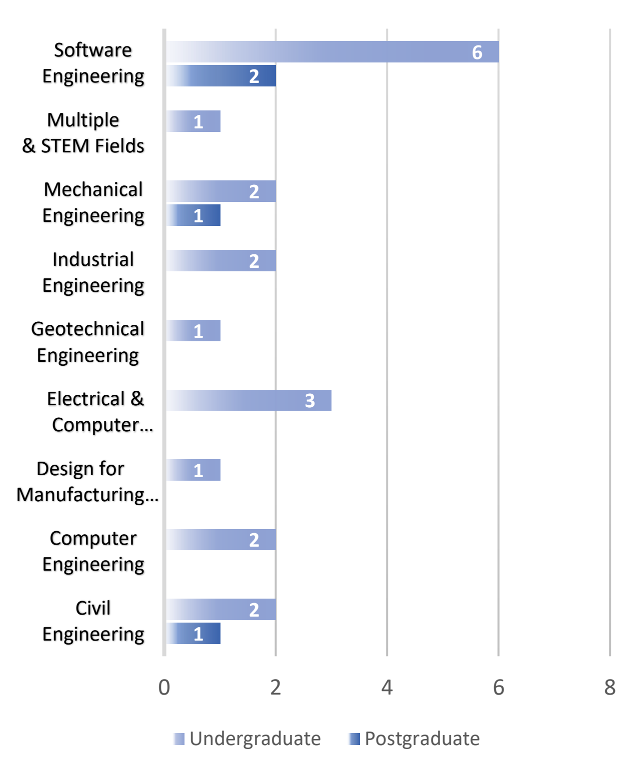

Figure 5. Distribution of Academic Level by Engineering Field

B. Goals for Using Game-Based Learning in Engineering Education and Their Impact on Game and Platform Selection

Table 1 shows the diverse objectives of GBL in EE, which guide the choice of game types and platforms. Key aims include enhancing student motivation and understanding through formats like serious games on platforms like Unity (Ivanova et al., 2019; Velaora & Kakarountas, 2021); supporting skills development with tools such as simulations across both digital and tabletop settings (Cook-Chennault & Villanueva, 2019; Lui et al., 2019); and improving engagement and practical skills via immersive technologies like augmented reality (Gordillo et al., 2020; Ibrahim et al., 2019). Additionally, the use of educational games and tools like LEGO Serious Play assesses and boosts educational outcomes, while innovative approaches such as virtual reality advance the frontier of technology in education (Oren et al., 2021; Sousa, 2020; Cook-Chennault & Villanueva, 2019). This variety of objectives and platforms highlights GBL's adaptive use in EE, tailored to specific learning outcomes and engagement strategies.

Table 1. Summary of GBL in EE: Objectives, Genres, Types, and Platforms

Common Objective	Game Genre	Type	Playable Platform
Enhance Motivation and Understanding	Mixed Games, Serious Game, Tic-Tac-Toe, Strategy Games	Mixed, Digital	Various, Web applications, Unity
Support Learning and Skills Development	Simulation, Hands-On Simulation, Business Simulation, Educational App	Digital, Non-Digital	Web-based browsers, Table-top, Web-based
Improve Engagement and Practical Skills	Escape Room, Serious Games, Augmented Reality	Digital, Non-Digital	Escapp platform, Unity, Mobile App
Explore and Assess Educational Game Impact	Educational Video Game, Board Games, LEGO Serious Play	Digital, Non-Digital	3-D role-playing, Physical board games, Physical LEGO bricks
Innovative Learning Experiences and Tools Utilization	Puzzle Game, Virtual Reality, Simulation, Storytelling	Digital	Computer-based platforms, Mobile devices

C. Key Design Features and Standards for Developing Game-Based Learning Tools and Their Application in Engineering Courses

Table 2 outlines the primary game features, design frameworks, and implementation strategies for GBL tools in EE. Commonly identified design features include interactive gameplay, feedback mechanisms, 3D environments, interdisciplinary learning elements, role-playing, and narrative storytelling, enhancing engagement and personalized learning. For example, Gordillo, López-Fernández & Tovar (2022) highlight the effectiveness of interactive gameplay, while Daskalogrigorakis et al. (2021) emphasize the importance of feedback mechanisms. Key frameworks guiding GBL development are educational game design principles, gamification principles, instructional design principles, learning theories, and serious games frameworks. Studies by Lui, Lee & Fung (2019) and Cuevas-Ortuño & Huegel (2020) illustrate how these frameworks ensure educational effectiveness. Educators employ various strategies to integrate GBL tools, including collaborative learning, online learning, drill and practice, and inquiry-based learning (IBL). For instance, Ivanova, Kozov & Zlatarov (2019) demonstrate the benefits of collaborative learning, while Evangelou, Kapsoulakis & Xenos (2023) discuss the use of GBL tools as supplementary resources. These elements collectively foster dynamic, interactive learning environments that address modern educational demands and prepare students for real-world engineering challenges.

Table 2. Primary Game Features, Design Frameworks, and Implementations of GBL in EE

Category	Common Characteristics/ Strategies	Related Reference
Design Features (Game elements incorporated in the game)	Interactive Gameplay	Gordillo, López-Fernández & Tovar (2022), Jain et al. (2022)
	Feedback Mechanism	Daskalogrigorakis et al. (2021), Oren, Pedersen & Butler-Purry (2021)
	3D Environment	Gill et al. (2023), Cui et al. (2023)
	Interdisciplinary Learning Elements	Evangelou, Stamoulakatou & Xenos (2021), Evangelou, Kapsoulakis & Xenos (2023)
	Role-Playing	Ivanova, Kozov & Zlatarov (2019), Jain et al. (2022)
	Narrative and Storytelling	Cuevas-Ortuño & Huegel (2020), Maisiri & Hattingh (2022)
Design Frameworks (Standards/ frameworks guiding the design and development of the game)	Educational Game Design Principles (e.g., clear learning objectives, in-game assessment)	Lui, Lee & Fung (2019), Cui et al. (2023)
	Gamification Principles (e.g., game mechanics, rewards)	Velaora & Kakarountas (2021), Hare, Tang & Zhu (2023)
	Instructional Design Principles (e.g., ADDIE, Agile)	Cuevas-Ortuño & Huegel (2020), Gill et al. (2023)
	Learning Theories (e.g., Constructivism, Experiential Learning Theory)	Velaora & Kakarountas (2021), López-fernández et al. (2021)
	Serious Games Frameworks (e.g., Input-Output GBL Model)	Ivanova, Kozov & Zlatarov (2019), Evangelou, Kapsoulakis & Xenos (2023)
Implementation Strategies (How educators use the games in their teachings)	Collaborative Learning	Ivanova, Kozov & Zlatarov (2019), Jain et al. (2022)
	Online Learning	Celorrio-Aguilera & Freire (2021), Gordillo, López-Fernández & Tovar (2022)
	Drill and Practice	Ivanova, Kozov & Zlatarov (2019), Daskalogrigorakis et al. (2021),
	Inquiry-Based Learning (IBL), Problem-Based Learning (PBL), Challenge-Based Learning (CBL)	Lui, Lee & Fung (2019), Cuevas-Ortuño & Huegel (2020)
	Supplementary Tool	Cook-Chennault & Villanueva (2019), Evangelou, Kapsoulakis & Xenos (2023)

D. Educational Outcomes of Game-Based Learning in Engineering Education and Methods of Investigation

Table 3 highlights the significant benefits of GBL in EE, documenting improvements across domains such as engagement, motivation, knowledge enhancement, satisfaction, and practical skills development. These benefits are consistently noted across various research designs. Engagement and motivation are frequently enhanced, as shown in mixed-methods studies employing surveys and qualitative feedback (e.g., Ivanova, Kozov & Zlatarov, 2019; Cook-Chennault & Villanueva, 2019). Knowledge and learning outcomes are also markedly improved, with methods ranging from quantitative to mixed, verifying learning gains through pre- and post-tests (e.g., Gordillo et al., 2020; Lui, Lee & Fung, 2019). GBL tools are generally found to improve learning experiences and satisfaction, as seen in both mixed methods and quantitative studies (e.g., Sousa, 2020; Evangelou et al., 2021). Additionally, GBL facilitates the development of practical skills, through mixed methods and qualitative inquiries (e.g., Daskalogrigorakis et al., 2021; Maisiri & Hattingh, 2022). Collectively, these outcomes underline GBL's comprehensive impact in enhancing not just academic performance but also student engagement, perceptions, and practical competencies in EE.

Table 3. Overview of GBL Educational Outcomes in EE: and Methodologies

Educational Outcome	Example of Findings	Research Design
Increased Engagement and Motivation	1. Increased interest in software engineering (Ivanova, Kozov & Zlatarov, 2019) 2. Motivation to learn G-code programming (Daskalogrigorakis et al., 2021) 3. Heightened engagement in	1. Mixed Methods (Primarily Quantitative) Example: Ivanova, Kozov & Zlatarov (2019): Surveys; qualitative feedback. 2. Mixed Method Sequential Exploratory Example: Cook-Chennault & Villanueva (2019):

	agile software development (Lui, Lee & Fung, 2019)	Questionnaire; focus group discussions.
Enhanced Learning Outcomes and Knowledge Acquisition	1. Improved test scores in software modeling (Gordillo et al., 2020) 2. Better understanding of requirements elicitation (Ibrahim et al., 2019) 3. Enhanced knowledge of agile principles (Lui, Lee & Fung, 2019)	1. Mixed Methods (Primarily Quantitative): Example: Lui, Lee & Fung (2019): Pre- and post-tests; surveys; observations. 2. Quasi-Experimental Example: Gordillo et al. (2020): Pre- and post-tests; surveys. 3. Quantitative Example: Ibrahim et al. (2019): Online questionnaires.
Improved Learning Experiences and Satisfaction	1. High engagement and enjoyment in civil engineering (Sousa, 2020) 2. Positive feedback for "My life as a software engineer" (Evangelou et al., 2021) 3. Fun and motivating LEGO Serious Play (López-Fernández et al., 2021)	1. Mixed Methods Example: Sousa (2020): Pre- and post-tests; surveys; observations. 2. Quantitative Example: Evangelou et al. (2021): Pre- and post-tests; SUS questionnaire.
Development of Practical Skills	1. Practical application of truss stability (Cook-Chennault & Villanueva, 2019) 2. Hands-on G-code programming experience (Daskalogrigorakis et al., 2021) 3. Real-world problem-solving in geotechnical engineering (Cui et al., 2023)	1. Mixed Methods Example: Daskalogrigorakis et al. (2021): Surveys; qualitative feedback. 2. Qualitative (Self-Reflective Inquiry) Example: Maisiri & Hattingh (2022): Reflective questions. 3. Quantitative Example: Cui et al. (2023): Pre- and post-tests.

Discussion

The systematic literature review revealed that GBL is predominantly utilized at the undergraduate level across various engineering disciplines, particularly in fields closely linked to digital technologies such as software and electrical engineering. The primary goals for implementing GBL include enhancing motivation and understanding, supporting skills development, and improving engagement and practical skills. Key design features identified include interactive gameplay, feedback mechanisms, 3D environments, interdisciplinary learning elements, role-playing, and narrative storytelling. GBL has shown significant positive impacts on student engagement, motivation, knowledge acquisition, learning experiences, and practical skills development, typically investigated using mixed-methods research designs.

The review found that GBL is more frequently used at the undergraduate level across diverse engineering fields, aligning with Alanne (2015) and Garcia et al. (2020), who noted the extensive use of GBL in software and computer engineering. However, our findings extend this understanding by highlighting GBL's broader applicability in other disciplines such as mechanical, electrical, and civil engineering. This broader application indicates that GBL is effective not only for early education stages but also across a variety of engineering fields, suggesting a universal appeal and adaptability of GBL in foundational engineering education. The quantitative analysis illustrated in Fig. 5 provided additional insights into the distribution of GBL usage across different academic levels and engineering disciplines.

The review identified that enhancing motivation and understanding, supporting skills development, and improving engagement and practical skills are primary goals for using GBL with impact in EE. This aligns with Despeisse (2018), who emphasized the cognitive and affective outcomes of games and simulations. The thematic analysis of objectives showed how different goals influence the choice of game genres and platforms, such as serious games and simulations, used to achieve specific educational outcomes. The integration of these tools helps address diverse learning needs and preferences, optimizing educational outcomes across various engineering disciplines. This comprehensive approach contrasts with studies focused solely on specific skills or fields, indicating the broader educational goals identified in this review. However, Garcia et al. (2020) primarily focused on soft skills development in software engineering, which may not fully capture the broader educational goals identified in our review.

In terms of design features and standards, the review identified interactive gameplay, feedback mechanisms, and 3D environments as key elements, consistent with the design principles discussed by Garcia et al. (2020) and Udeozor et al. (2022). Both studies emphasize the importance of these features in creating engaging and effective educational tools. The thematic analysis showed that interdisciplinary learning elements, role-playing, and narrative storytelling are crucial for developing comprehensive GBL tools that cater to varied educational contexts and enhance the overall learning experience. This comprehensive approach contrasts with Alanne (2015), who focused more on gamification elements like competition and rewards, indicating different design priorities based on educational contexts.

Our findings on the educational outcomes of GBL indicate significant improvements in student engagement, motivation, knowledge acquisition, learning experiences, and practical skills development. This is supported by Udeozor et al. (2022), who reported similar benefits from digital game-based learning. Our review expands on these findings by demonstrating that non-digital GBL tools also contribute to these positive outcomes, suggesting that the benefits of GBL are not limited to digital formats. This comprehensive impact underscores GBL's potential to enhance various aspects of EE, preparing students to meet the challenges of the modern workforce effectively.

Conclusion

This systematic literature review highlights the transformative potential of GBL in EE. GBL enhances student engagement, understanding, and skill development across various engineering disciplines and educational levels. It effectively adapts to diverse learning environments, meeting a wide range of educational needs. The integration of interactive gameplay, feedback mechanisms, and interdisciplinary elements makes GBL a versatile and powerful tool, significantly improving educational outcomes and preparing students for the challenges of modern engineering practice. This review contributes to the field by providing a comprehensive analysis of GBL's effectiveness and offering insights into its application, design features, and educational benefits, thereby guiding future research and implementation strategies in EE.

However, the review is limited by its reliance on a single database, IEEE Xplore, which, while comprehensive in its scope within engineering fields, may omit relevant studies available in other academic databases or journals. This could potentially skew the breadth and depth of analyzed data. Additionally, the restriction to English-language publications from the past few years may exclude valuable broader historical perspectives or relevant studies conducted in other languages.

Future research should aim to include multiple databases to capture a wider range of studies and consider including grey literature to provide additional insights into emerging trends and practical implementations of GBL. Expanding the linguistic scope of the literature search and extending the temporal range could uncover more diverse and comprehensive insights into the use of GBL in EE.

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