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Research Trends and Intellectual Structure of Game-Based Learning in Engineering Higher Education: A Bibliometric Analysis

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ABSTRACT

Game-based learning plays an increasingly vital role in engineering education. Driven by the recent surge in empirical studies demonstrating its effectiveness in this domain, this study aims to examine the structural framework, growth trajectory, and major contributors of the field through quantitative bibliometric analysis.

That's the gap this paper addresses. We filtered the Web of Science database using PRISMA, then analysed 392 documents in VOS viewer. Publication numbers have grown steadily since 2010, though growth in recent years has been uneven. A co-authorship analysis put the United States, Spain, Germany, and the United Kingdom at the front of the pack. At the institutional level, European universities such as Universidad Politécnica de Madrid and Politecnico di Milano lead the way, and universities in Spanish-speaking countries (Spain, Mexico, Ecuador) stand out. Keyword co-occurrence analysis split the field's intellectual structure into 5 thematic clusters. "Computer science" sits at the centre. Purely engineering terms like "mechanical engineering" and "engineering ethics," by contrast, sit out at the edges. Performance analysis backs this up: most of the top 10 journals are computer science conference proceedings. And an overlay map shows "engineering education" as one of the earliest core topics studied, while "game-based learning," "computer security," and "control (management)" have only recently picked up steam.

By conducting this study, computer science specialists will be able to work more closely with engineering faculty to develop interactive game-based learning (GBL) environments and simulations, making abstract engineering theories clearer and more engaging for students.

Keywords: Game-based learning; Engineering education; Bibliometric analysis; VOS viewer; Co-authorship analysis; Keyword co-occurrence

INTRODUCTION

Game-based learning enhances problem-solving skills allowing students to visually interact with and experiment with physical phenomena in virtual environments rather than just reading about them, bridging theory with practice (Agustina et al., 2024; Lampropoulos et al., 2025). Furthermore, this will strengthen interdisciplinary

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collaboration combining software development with engineering pedagogy to create more effective curricula and provide researchers and educators in developing nations a stronger participation in this field. Small wonder research in this space has taken off in recent years (Padilla Perez & Keleş, 2025).

Fields mature. They rack up hundreds of articles. And once that happens, bibliometric analysis becomes the sharpest tool available for mapping structure and trajectory (Passas, 2024). Usually, step one is simple: track historical publication trends, then identify which countries or journals carry the most influence (Donthu et al., 2021).

Still, earlier reviews of game-based engineering education leave some gaps. Raja Rosli and colleagues (2024) built their systematic review on a single database, IEEE Xplore, and sorted studies only by academic level and engineering discipline. They admit as much themselves: no quantitative bibliometric measure of country or time trends. Udeozor and colleagues (2023) found GBL applied across 13 engineering disciplines, but the coverage was lopsided. Software engineering dominated; many other fields barely got a look. That points to a real need for a more systematic, wider synthesis (Udeozor et al., 2023). Then there's Akhmetova and colleagues (2025), whose recent bibliometric study found GBL's thematic structure shifting in maturity depending on the database used and flagged the practical value of spotting research gaps early (Akhmetova et al., 2025). Their work is broad, covering 34,125 cross-disciplinary documents, and genuinely useful. But their search wasn't limited to engineering, so it can't isolate what makes engineering education distinct. And engineering education differs from GBL research in health, business, or general education in methodology, in goals, and in who the learners even are (Raja Rosli et al., 2024; Udeozor et al., 2023). That difference is worth studying on its own terms. So we picked 392 documents that met targeted criteria for engineering education and dug into the country, institution, and journal levels. The payoff: patterns a broader review would likely miss, like core engineering terms sitting at the edge of the network rather than the centre.

Our research questions are the following:

1. How has the volume of research on game-based engineering education grown over time, and which countries lead this research?

2. Which thematic clusters and intellectual structures dominate research on the use of games in engineering higher education?

3. What new topics and technologies have trended in this field in recent years, and where is future research heading?

Theoretical Background: Why does game-based learning actually work? Educational psychology and pedagogy offer a handful of answers. Self-Determination Theory says intrinsic motivation grows when a learner's needs for autonomy, competence, and relatedness are met (Guay, 2021). Educational games hit those needs by giving players choice and a sense of accomplishment (Proulx & Romero, 2016). Flow theory was originally introduced by the Hungarian American psychologist Mihaly Csikszentmihalyi and later further developed by others (Riaz & Ahmad, 2023). It describes a state in which a challenge perfectly matches an individual's skill level, capturing their complete interest—causing players to lose all sense of time, become fully absorbed and focused, and seamlessly transition into a state where nothing else distracts them (Perttula et al., 2017). Vygotsky's sociocultural theory zeroes in on social interaction within the gaming environment. Constructivist theory emphasizes that learners are active subjects who construct new concepts and knowledge themselves, rather than passively receiving them (Rigopouli et al., 2025). Meanwhile, Gardner's theory of multiple intelligences argues for designing games tailored to different learning styles (Akhmetova et al., 2025).

These theories serve as the foundation for developing game-based learning methodologies in engineering education and are also applied to help students master abstract and conceptual mechanical topics, such as force equilibrium and kinematic motion. Games make them visible.

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RESEARCH METHODOLOGY

We built the search terms in two stages. First, terms tied to games and engineering education, drawn from prior systematic reviews (Udeozor et al., 2023; Raja Rosli et al., 2024; Wang et al., 2022): ["game-based learning" OR "serious game" OR "digital game" OR "educational game" OR "computer game" OR "video game" OR "simulation game" OR "online game" AND "engineering education" OR "engineering"]. Then we added terms defining the higher education scope: ["higher education" OR "undergraduate" OR "university" OR "tertiary education"]. That kept the search focused on university-level learners, in line with this study's interest in adult students taking mechanics courses.

Applying the search criteria pulled 749 documents from Web of Science. Feeding that into VOS viewer for mapping knocked out 330 documents with missing data. From the remaining 419, we cut 16 published before 2010, since GBL only started taking off after that point (Akhmetova et al., 2025), plus 11 secondary studies, bibliometric analyses, systematic reviews, and meta-analyses, to keep the focus on primary empirical work. That left 392 documents, analysed with VOS viewer.

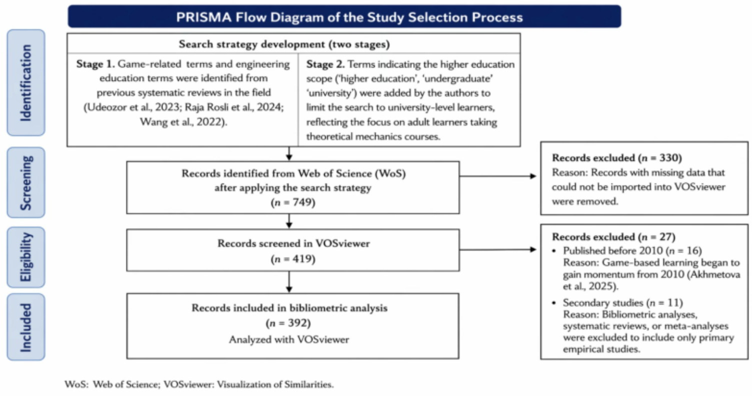
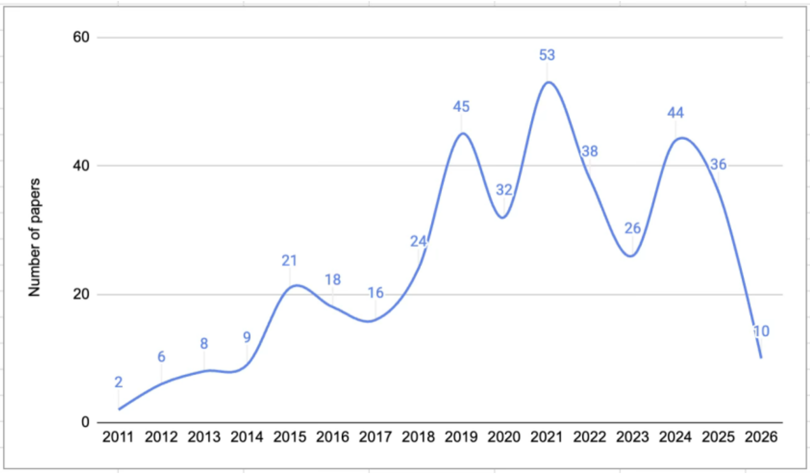


Figure 1. PRISMA flow diagram of the study selection process

To answer the research questions, we ran the following analyses in VOSviewer: for RQ1, co-authorship analysis of country collaboration networks; for RQ2, keyword co-occurrence analysis to surface the field's intellectual structure; for RQ3, an overlay visualization tracking trends over time. We also ran citation analysis at the Sources and Authors level to pin down the field's leading journals and authors, plus co-authorship analysis at the Organizations level. Thresholds: at least 5 documents for journals, 3 for authors, 3 for institutions.

RESULTS



Increasing result in research papers and countries

Figure 2. Total publications on game-based engineering education, annually (2010–2026)

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The volume of research articles has grown substantially over the last decade and a half. Before 2010, only 2 to 9 documents came out per year. By 2015, that number topped 20. Peaks hit in 2019 (45), 2021 (53), and 2024 (44). The growth is uneven but sustained, and it lines up with what Akhmetova, and colleagues (2025) found: GBL took off after 2010. (Note: 2026 data only run through July, so it's not a full-year figure.)

So which countries are driving that growth? A co-authorship network analysis puts the United States, Spain, Germany, and the United Kingdom out front, each showing up as the largest nodes in the network. Bigger nodes, under bibliometric theory, mean more publications and greater influence in the field (Raan, 2008).

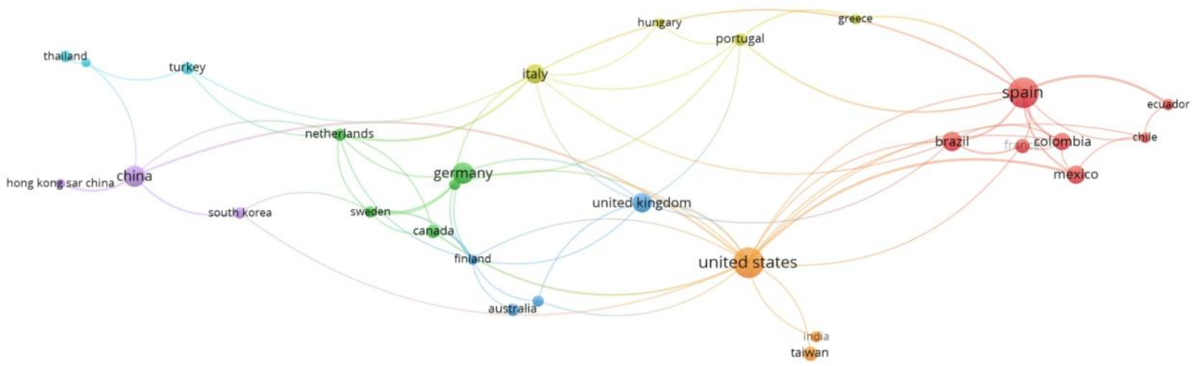

Figure 3. Country collaboration network in game-based learning and engineering education research

To check the country-level pattern against a finer institutional lens, we ran a co-authorship analysis at the Organizations level, institutions with at least 3 documents.

Table 1. Top 10 institutions (ranked by documents)

No.	Institution	Country	Documents	Citations
1	Universidad Politécnica de Madrid	Spain	6	212
2	Politecnico di Milano	Italy	6	98
3	Universidad Complutense de Madrid	Spain	5	96
4	Central University of Ecuador	Ecuador	5	6
5	Tecnológico de Monterrey	Mexico	5	13
6	Technological University of the Mixteca	Mexico	4	199
7	Universidad de Alcalá	Spain	4	81

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8	Universitat Politècnica de València	Spain	4	78
9	University of Twente	Netherlands	4	54
10	Universidad de Extremadura	Spain	4	53

Table 1 shows something striking: 6 of the top 10 institutions are universities in Spanish-speaking countries, Spain, Mexico, and Ecuador. That confirms, at the institutional level, the tight Spanish Latin American cluster visible in Figure 3. Universidad Politécnica de Madrid (6 documents, 212 citations) and Politecnico di Milano (6 documents, 98 citations) top the list, which says European technical universities lead the field institutionally, not just nationally. For our country, the takeaway is clear: developing a games-based methodology for engineering mechanics means studying how different regional and linguistic-cultural groups have approached it, then adapting that to our own context.

Thematic Clusters and Intellectual Structure

To pin down the intellectual structure of research on using games in engineering higher education, we ran a keyword co-occurrence analysis. With a threshold of at least 10 occurrences, 72 keywords emerged, splitting into 5 core thematic clusters.

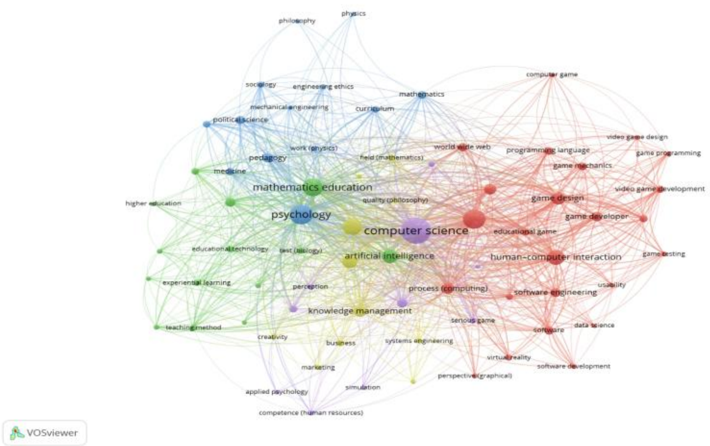

Figure 4. Thematic structure of game-based engineering education research

The results show the red cluster, game development, and human-computer interaction as the largest, most distinct group. It covers terms like "game design," "game developer," "video game development," "software engineering," and "virtual reality." The pink node, "computer science," has the biggest footprint in the whole network and sits as a hub connected to nearly everything else. That's the technical backbone of this research field. The teal or green cluster holds pedagogical and learning-theory concepts, "psychology," "mathematics education," "educational technology," and "experiential learning." The blue cluster carries core engineering education terms: "curriculum," "pedagogy," "mechanical engineering," and "engineering ethics." And the yellow cluster centers on knowledge management and applied skills, "artificial intelligence," "knowledge management," "systems engineering," "simulation."

Here's the most telling result: keywords with a distinctly engineering flavor, "mechanical engineering," "engineering ethics," "systems engineering," all sit at the edge of the network, with small nodes to match. In practice, that means research on using games in engineering higher education runs more on computer science and game development discourse than on core engineering topics. Udeozor and colleagues (2023) noted that GBL gets applied across many engineering disciplines- mechanical, electrical, civil, you name it- but the

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methods tend to lean on computer science tools and platforms. This intellectual structure map backs that up (Udeozor et al., 2023).

Performance Analysis: Leading Journals and Authors

To confirm the intellectual structure at the journal and author level, we ran citation analysis separately for Sources (at least 5 documents) and Authors (at least 3 documents).

Table 2. Top 10 journals (ranked by citations)

No.	Journal	Documents	Citations	Avg. Citations/Document
1	Journal of Chemical Education	8	315	39.4
2	Computer Applications in Engineering Education	9	249	27.7
3	Sustainability	5	196	39.2
4	IEEE Transactions on Education	7	147	21
5	Lecture Notes in Computer Science	21	138	6.6
6	International Journal of Emerging Technologies in Learning (iJET)	5	116	23.2
7	IEEE Access	5	77	15.4
8	Advances in Intelligent Systems and Computing	9	57	6.3
9	Communications in Computer and Information Science	8	45	5.6
10	Lecture Notes in Networks and Systems	12	17	1.4

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Table 3. Top authors (ranked by citations)

No.	Author	Documents	Citations	Avg. Citations/Document
1	Iván García	4	199	49.8
2	Carla Pacheco	3	178	59.3
3	José A. Calvo-Manzano	3	178	59.3
4	Chioma Udeozor	3	153	51
5	Fernando Russo Abegão	3	153	51
6	Jarka Glassey	3	153	51
7	Amarpreet Gill	4	21	5.25
8	Dave Towey	4	21	5.25
9	Linjing Sun	4	21	5.25
10	Derek Irwin	3	21	7

Table 2 tells a similar story. Most of the top 10 journals, "Lecture Notes in Computer Science," "Advances in Intelligent Systems and Computing," "Communications in Computer and Information Science," and "IEEE Access," are computer science conference proceedings. That confirms, at the journal level, the "computer science" hub we saw in the keyword analysis. Most research output concentrates in computer science, not just in content but in where it gets published. Journals like Journal of Chemical Education and Sustainability buck the trend: fewer papers, but the highest citations per document (39-plus each). Small volume, big influence.

A prominent observation is that key authors listed in Table 3—namely Chioma Udeozor, Fernando Russo Abegão, and Jarka Glassey—co-authored the study by Udeozor et al. (2023), which previously contextualized the present research gap. Their systematic review holds significant weight in this literature corpus, generating 153 overall citations and averaging 51 citations per item.

Temporal Trends and Emerging Focal Areas

To identify trending topics and novel technologies, a temporal overlay map was constructed via VOS viewer. Node coloration indicates the average publication timestamp of keyword occurrences, where blue/purple shades denote established topics (around 2019) and yellow nodes signify recent scholarly focus (around 2020.5).

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Figure 5. Temporal mapping of keyword co-occurrences in game-based engineering education research (overlay visualization)

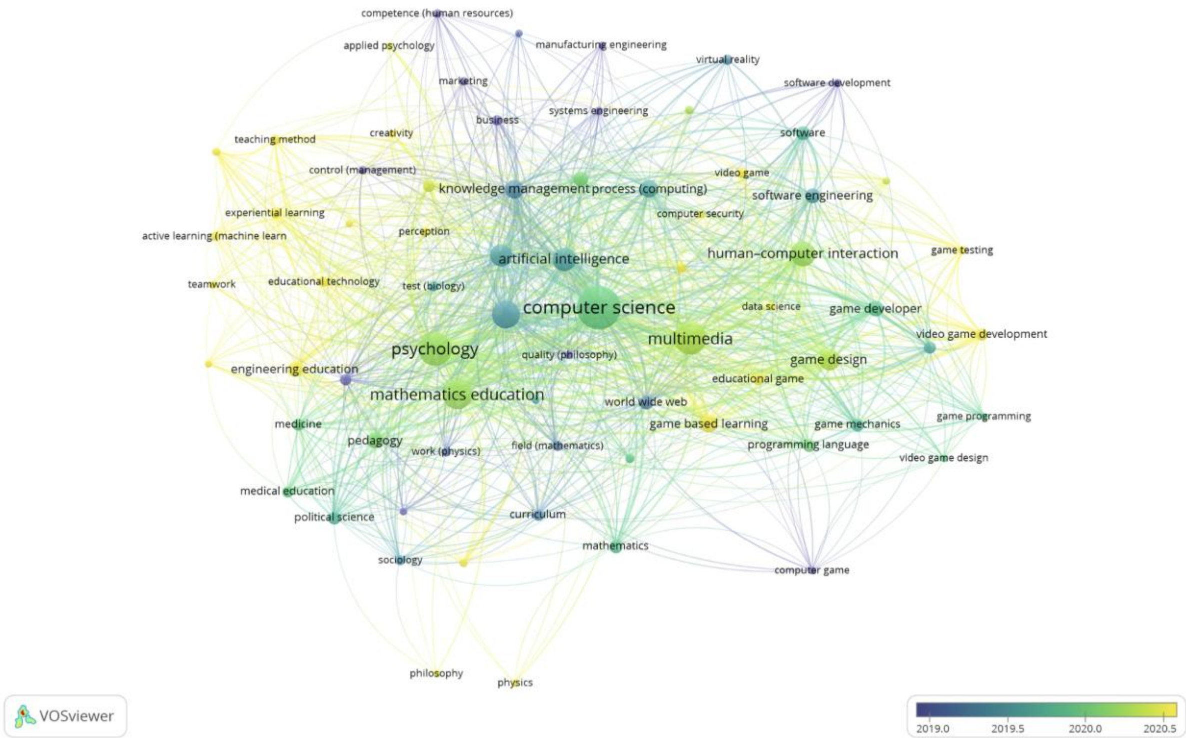

Figure 5. Temporal evolution of keywords in game-based engineering education research (overlay visualization)

Keywords like "game-based learning," "computer security," "control (management)," "teaching method," "physics," "computer game," "perception," and "creativity" show up bright yellow, marking them as trends that have picked up in recent years. Terms like "engineering education," "manufacturing engineering," "applied psychology," "competence (human resources)," "business," and "marketing," on the other hand, appear in blue/purple: the earliest-studied, most stable topics.

That points to something bigger: recent research is drifting away from the broad, general term "engineering education" toward sharper, more technical terminology. The field's language is shifting from general-academic to specific and applied. Worth noting, too: "virtual reality," which came up in the research questions, has a relatively early average timestamp (around 2019.3). VR isn't a new topic in engineering education. It's already an established research direction.

DISCUSSION AND CONCLUSION

Through bibliometric evaluation of 392 publications, this study answers the core research questions by highlighting congruent patterns in scholarly output, geographic dispersion, and thematic trends. The convergence of these trends across macro (national), meso (institutional), and micro (journal) levels substantiates the robustness of the derived findings.

Publication counts have climbed steadily since 2010, but not in a straight line. Peaks came in 2019, 2021, and 2024, with dips in between, a sign that this research area needs more sustained attention going forward. The countries leading the co-authorship analysis, the US, Spain, Germany, and the UK, likely got there partly through heavier national funding and infrastructure for higher education and R&D over the past decade (Leydesdorff & Wagner, 2009). The institutional analysis backs this up: universities in Spanish-speaking countries lead there too. A significant finding is the limited involvement of developing countries like Mongolia, which occupy a marginal role in the research landscape. This underscores the necessity of leveraging internationally validated game-based frameworks while contextualizing them for national engineering education needs. Additionally, the

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co-occurrence analysis highlights that domain-specific keywords—namely 'mechanical engineering,' 'engineering ethics,' and 'systems engineering'—remain at the outer boundaries of current literature trends. The keyword co-occurrence analysis turned up its most telling result here: keywords with a distinctly engineering flavor, "mechanical engineering," "engineering ethics," "systems engineering," sit at the network's edge. Performance analysis backs this with hard numbers. Most of the top 10 journals are computer science conference proceedings, meaning computer science dominates not just the content but the publication venues too. Three things explain this. First, game-based learning is, at its core, a software product, so search results naturally skew toward computer science discourse. Second, building a game takes technical skill, so the research tends to involve software or computer engineering specialists, while mechanical and civil engineers mostly show up as end users (Udeozor et al., 2023). Third, since the field's leading journals are computer science proceedings, researchers tend to adopt their terminology. That helps explain something from the theoretical background section: why GBL's educational-psychology and pedagogical frameworks still haven't fully captured what makes engineering thinking distinct. And that raises a real, practical concern. Unless engineering education researchers, mechanical engineering ones especially, get actively involved and bring their own disciplinary lens to the table, game-based pedagogy risks developing around models built by computer science researchers instead of what engineering actually needs.

The overlay visualization backs this up further. "Engineering education" shows up on the node map as the earliest-studied general term. Recent research looks to have moved away from broad, general terminology and toward more specialized, discipline-specific language.

Consolidating these four analytical perspectives underscores a clear trend: despite the quantitative growth of GBL research in engineering, knowledge generation is largely confined to select regions and academic institutions, with computer science maintaining a central role in literature and venues. To effectively implement GBL in national engineering education, this study highlights three imperatives: (1) adapt internationally proven models to local institutional contexts; (2) facilitate cross-disciplinary collaboration between CS and engineering educators to align game design with mechanical engineering competencies; and (3) examine how subjects like control systems and cybersecurity can be embedded into mechanical engineering instruction. One limitation worth flagging: this study relied solely on Web of Science, which may have left out relevant studies indexed elsewhere, such as Scopus. It also only covered English-language publications, so work published in other languages, especially from non-English-speaking countries, is probably underrepresented.

Future work should bring in additional databases like Scopus for comparison and should include practical case studies on introducing GBL into engineering education in specific developing countries. Empirical research on adapting game-based learning methods for mechanical engineering to a country's own education system would go a long way toward closing this field's theory-practice gap.

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