

Engineering Learning Through Play: Insights from a Systematic Review and Meta-Analysis of Digital Games in Higher Education

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Abstract

In this systematic review and work-in-progress meta-analysis, we seek to enhance our understanding and guide the future direction of games in engineering education by leveraging existing discoveries and linking them to informed decision-making for educators, policymakers, and game developers in the engineering field. We conducted a systematic review of major electronic databases, including ERIC, Academic Search Ultimate, APA PsycInfo, using keywords related to digital game-based learning (DGBL), engineering, higher education, and learning outcomes. Our initial search identified 3,195 peer-reviewed studies published between 1993 and 2024. Our inclusion criteria focused on empirical studies that utilized DGBL interventions in formal or informal engineering educational settings. A full breakdown of this process will be given via PRISMA diagram. The screening process involved several stages. Studies were reviewed by at least two researchers and included if they reported quantitative data on engineering student achievement, engagement, or attitudes toward DGBL. Each study underwent coding using established criteria (e.g., sample size, research design, and control group comparability), and relevant data (e.g., effect sizes, sample characteristics, and intervention details) were extracted from each study. After the full screening, a total of 36 studies met inclusion criteria. These studies encompassed a wide range of DGBL formats in higher education, including serious games, simulations, human-computer interaction and digital gamified learning environments. Sample sizes ranged from small-scale classroom experiments ($n = 17$) to large-scale randomized controlled trials ($n = 774$). Our in-meta-analysis revealed several preliminary key findings. Overall, DGBL interventions demonstrated a moderate positive effect on engineering learning outcomes. Visuals of these effects will be shared in our presentation. Students exposed to DGBL consistently outperformed their peers in traditional instructional settings. Additionally, the impact of DGBL varied across different engineering domains and degree levels and positively influenced student motivation and engagement in several studies. The interactive nature of games fostered intrinsic motivation and sustained interest in engineering topics. Our meta-analysis underscores the potential of DGBL in enhancing engineering education. Educators should consider integrating well-designed games into their curricula. However, challenges remain, such as ensuring equitable access to technology and addressing concerns about screen time. Future research should explore optimal game design principles, personalized learning pathways, and long-term effects of DGBL.

Keywords: game-based learning, educational technology, higher education, systematic review, instructional methods

Motivation and Background

Game-based learning (GBL) has gained prominence as an innovative approach to education, particularly in the engineering discipline. As digital technologies continue to evolve, educators and researchers seek evidence-based insights into the effectiveness of GBL interventions. This proposed meta-analysis aims to synthesize existing research, providing a comprehensive overview of the impact of GBL on engineering learning outcomes. This paper contributes uniquely by calculating overall effect sizes in learning outcomes in college-level

engineering using digital (non-physical) game-based learning (DGBL). This analysis categorizes those learning outcomes into two groups: cognitive and affective. Learning measures in the cognitive category include course and task performance, knowledge tasks, and computational thinking. Learning measures in the affective category include learning motivation, course engagement, and involvement.

Digital game-based learning (DGBL) is an innovative approach that integrates digital video games into educational contexts [1]. DGBL involves using games to facilitate learning processes or outcomes [2]. DGBL can motivate students by making learning enjoyable and dynamic while fostering active participation and sustained interest in educational materials by incrementally introducing concepts, guiding users toward specific learning goals [3]. It provides opportunities for lifelong learning by integrating social skills, knowledge training, and collaborative learning and positively impacts mindset and growth [2].

Despite the growing interest in integrating game-based learning into engineering education [4], a notable deficiency persists in the availability of comprehensive meta-analyses or literature reviews on the subject. Udeozor et al., in 2023 conducted a systematic review on digital games in engineering education, where they explored the application of DGBL in engineering education. This study focused on discovering the number of articles that used DGBL in engineering education [5] but does not analyze effect sizes or experimental outcomes.

While individual studies often highlight the potential benefits of utilizing gaming technologies in engineering pedagogy [6], the absence of synthesized and critically analyzed data poses a significant obstacle for educators and researchers seeking evidence-based insights. This hinders the ability to draw definitive conclusions regarding the effectiveness, applicability, and best practices of game-based learning in engineering education. Addressing this gap by analyzing the effect sizes and drawing a conclusion based on the published literature will enhance the evidence in the field of engineering education.

Methods

We conducted a systematic review of 3,195 peer-reviewed studies published between 1993 and 2024. We systematically searched electronic databases (ERIC, Academic Search Ultimate, which includes the IEEE Proceedings, IEEE Transactions on Education records, and ASEE Annual Conference & Exposition Proceedings, APA PsycInfo, British Education Index, Education Full Text, Psychology and Behavioral Sciences Collection, Social Sciences Full Text, SocINDEX with Full Text, Sociology Source Ultimate, Education Source, Education Source Ultimate, and Engineering Source). Keywords used were: ("Game-based learning" OR gbl OR "serious game" OR "digital game") AND (engineering OR engineer OR "computer science" OR "industrial distribution") AND (student or undergraduate or university or college) AND (academic OR knowledge OR cognitive OR affective OR perceptions OR interest OR belief OR grade OR test OR survey).

Screening Process

Our inclusion criteria focused on empirical studies that utilized DGBL interventions in formal or informal engineering undergraduate and graduate level educational settings. Studies were

included if they reported quantitative data on engineering student achievement, engagement, or attitudes toward GBL.

We used Rayyan to import and screen our records. The research team consisted of 5 undergraduate students, 2 graduate students, and the associate research scientist acting as supervisor. Our exclusion criteria were certain publication types such as case reports and literature reviews, gamification, other common uses of the abbreviation of “GBL,” animal studies, elementary, middle, and high school/secondary students, and medical-related articles. Every article was reviewed by at least 2 people on the team and voted to include or exclude. In the case of a conflict on the inclusion/exclusion decisions, 4 of the authors of this paper met in person and unanimously resolved the conflict. After conflicts were resolved ($n = 249$), articles were reviewed for sample size, research design, control group comparability, relevant data (e.g., effect sizes, sample characteristics, and intervention details) and the information was extracted from each study. A PRISMA flow diagram of our screening process is provided in Appendix A.

After screening, we identified 36 relevant studies that met our criteria. These studies encompassed a wide range of DGBL formats, including serious games, simulations, human-computer interaction and digital gamified learning environments.

Initial Results

By the time of submission, a total of 21 studies were used to calculate Cohen’s d effect sizes. Sample sizes ranged from small-scale classroom experiments ($n = 17$) to large-scale randomized controlled trials ($n = 774$). Our preliminary analysis revealed several key findings: By the simple weighted arithmetic mean, DGBL interventions demonstrated a moderate positive effect on engineering learning outcomes. Those who experienced DGBL outperformed those who experienced traditional instructional settings by about a fifth of a standard deviation cognitively. Affectively, those who experienced DGBL outperformed those who experienced traditional instructional settings by about a third of a standard deviation. In addition to that, DGBL positively influenced student motivation and engagement. The interactive nature of games fostered intrinsic motivation and sustained interest in engineering topics. By the time of submission, 36 cognitive effect sizes were calculated across 18 studies and 35 affective effect sizes were calculated across 8 studies. Measures of variation and summary statistics are provided in Table 1 below. A heterogeneity assessment will be conducted to determine which meta-analysis method we will use. We will choose between a random effects and a fixed effect model, and we will include a forest plot.

Cohen’s d Effect Sizes						
Category	Weighted Mean	Low	Quartile 1	Median	Quartile 3	High
Cognitive	0.177	-1.748	-0.027	0.402	1.060	3.844
Affective	0.322	-0.704	-0.048	0.316	0.718	2.541

Table 1: Measures of variation and summary statistics of calculated effect sizes.

Implications and Future Directions

Our preliminary analysis underscores the potential of DGBL in enhancing engineering education. However, challenges remain, such as ensuring access to technology. Future

research should explore the effects on learning outcomes of various game design elements, personalized learning pathways, and long-term interactions with DGBL. The continuation of this work for this project will also investigate how certain factors influenced the magnitude of DGBL effects. These included the type of game (e.g., immersive simulations vs. quiz-based games), duration of exposure, and learner characteristics (e.g., prior knowledge and degree level). Moreover, we will measure how the impact of DGBL varied across different engineering domains. DGBL appears to hold promise as a pedagogical tool that bridges theory and practice in engineering education. By situating new findings within the context of prior research, this meta-analysis contributes to evidence-based decision-making for educators, policymakers, and game developers.

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Appendix A

PRISMA flow diagram for new systematic reviews which included searches of databases

