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The Development and Effectiveness Evaluation of Game Labs in Learning: Content Analysis and the Impact of Gamification

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Abstract

This study examines the development and effectiveness evaluation of game labs in learning through a Systematic Literature Review (SLR) approach. Game labs, or laboratories that incorporate gamification elements, offer an innovative solution to create interactive and safe learning experiences. The urgency of this research is based on the need for more adaptive education to enhance student engagement and understanding, especially in practical learning that requires a high level of safety. The purpose of this study is to identify development trends, included content, and the effectiveness of game labs in supporting student motivation and understanding across various disciplines, such as biology, chemistry, mechanical engineering, and cybersecurity. The results show that game labs using gamification elements like challenges, 3D visualization, and rewards can significantly increase student engagement and understanding. Game labs also allow students to explore in a controlled environment, fostering motivation and independent learning. In conclusion, game labs are effective in enriching the learning experience and are relevant for widespread implementation to meet the needs of more innovative and interactive learning.

1. INTRODUCTION

It is undeniable that the advancement of global technology has had a significant impact on various aspects of life, especially education. In this digital era, technology has developed rapidly alongside the progress of science, and its integration into the education sector has drastically transformed teaching and learning methods. Technology is no longer just a supporting tool but has become a primary medium for delivering more interactive and efficient learning materials. Every new invention aims to provide optimal benefits for humanity, including ease of access to information and improvements in the quality of learning. Over the past few decades, these innovations have brought significant changes to traditional educational methods, enriching learning experiences and increasing the effectiveness of the educational process at all levels, from primary to higher education [1].

One innovative approach that is increasingly being applied in education is the use of game labs, which integrate game elements into educational laboratory environments to enhance students' motivation and engagement. According to Growth Engineering, the global gamification market is projected to grow from $9.1 billion in 2020 to $30.7 billion by 2025, with a compound annual growth rate (CAGR) of 27.4%. Furthermore, data from Market Data Forecast reveals that the gamification market in education specifically is expected to reach $13.66 billion by 2032, with a CAGR of 36.4%. These figures indicate that the application of game elements in education is becoming a global trend. The adoption of gamification methods in education is also on the rise, as they have been proven to positively impact students' learning experiences. Gamification in education has been shown to create a more enjoyable and engaging learning experience [2].

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The use of gamification elements in education has been proven to increase student participation. For instance, 67% of students in the United States prefer educational methods that include game elements, such as rewards and competition, which boost their engagement. However, one of the major challenges in education is the lack of student motivation. This issue often arises when learners do not clearly understand the purpose of a learning activity or perceive the material as irrelevant to them. Traditional teaching methods often fail to align with the nature of scientific concepts and are increasingly out of touch with the digital era. Many students find it difficult to grasp these concepts and recognize their importance [3][4]. This situation can lead to low student engagement in the learning process, difficulties in understanding information, and failure to achieve desired educational goals [5].

Gamification holds great potential, but there are challenges in its implementation. One major obstacle is the lack of clear guidance on how gamification elements can be effectively integrated into learning materials. Additionally, there is insufficient comprehensive research on the effectiveness of game labs, particularly in secondary schools. This has created a gap in the literature, especially regarding the direct impact of gamification on learning outcomes.

This research is essential to address these gaps by providing a systematic review of the development and use of game labs. By addressing these needs, this study aims to make a significant contribution to the field of education, both as practical guidelines and as a theoretical foundation for further research.

The study aims to fill these gaps using the Systematic Literature Review (SLR) method. This approach enables researchers to: (1) Identify game labs developed by researchers over the past decade. (2) Review the content within game labs. (3) Evaluate the effectiveness of gamification elements in supporting learning. Through the analysis of existing literature, this research is expected to provide deeper insights into how game labs can be effectively utilized in education. Furthermore, the findings of this study are expected to assist educators and educational application developers in designing more interactive game labs that meet current learning needs. This research also aims to enrich the literature on gamification in education and provide a theoretical basis for future research.

2. RESEARCH METHOD

This study employs a Systematic Literature Review (SLR) approach to identify, review, and analyze literature relevant to the research topic. SLR is a systematic and transparent method for collecting and evaluating various studies relevant to the research objectives. This process follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [6].

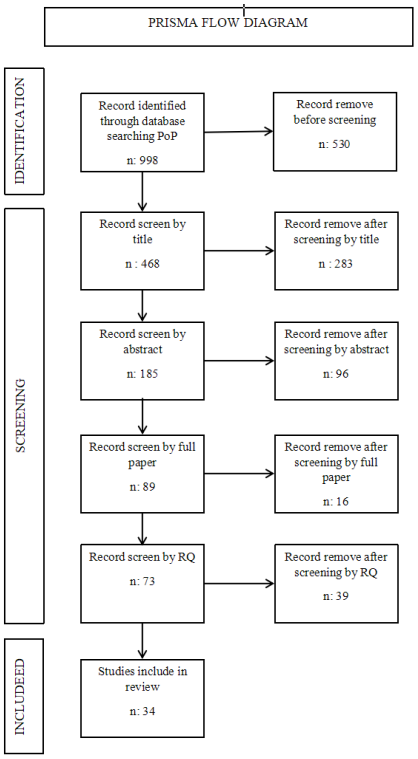

Figure 1. PRISMA Diagram

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2.1 Article Identification

The first step in this study is to identify literature relevant to the research topic. This process is carried out through systematic searches across multiple scientific databases using predefined keywords.

a. Search Databases
   The search was conducted using popular databases such as Google Scholar, IEEE Xplore, Scopus, and others to ensure broad and relevant literature coverage.
b. Search Keywords
   After determining the databases, the researchers defined the keywords used, including relevant terms related to the topic, such as: "game lab," "game OR gamification and lab or laboratory or labor."
c. Inclusion and Exclusion Criteria
   1) Inclusion Criteria: Articles focusing on the use of game labs and gamification in education, published between 2014 and 2024, and articles providing empirical data or in-depth analysis.
   2) Exclusion Criteria: Articles that are irrelevant, do not provide empirical data, or fall outside the specified time frame.

The search conducted on September 27, 2024, resulted in 998 articles from various databases.

2.2 Screening (Article Filtering)

After the identification process, articles went through several screening stages:

Stage 1: Title-Based Screening, Of the 530 identified articles, 468 were selected for the next screening stage, with 283 articles removed for lack of relevance based on title assessment.

Stage 2: Abstract-Based Screening, From the 468 articles, 185 were selected for further evaluation through abstract screening, with 96 articles removed at this stage due to irrelevance to the research questions.

Stage 3: Full Paper Screening, Articles that passed the abstract screening were further examined based on full content. A total of 89 articles were selected for in-depth review, with 16 articles removed after full content evaluation.

Stage 4: Screening Based on Research Questions (RQ), At this stage, articles were further screened for relevance to the research questions. A total of 73 articles were evaluated, with 39 articles removed for not aligning with the research questions.

2.3 Articles Included

After the screening process, 34 articles were selected for this literature review. These articles met all inclusion criteria, were directly relevant to the research topic, and provided data supporting further analysis related to the development and evaluation of game labs and the impact of gamification on learning.

2.4 Data Analysis

Once the relevant articles were identified, each article was analyzed in depth using the following steps:

a. Study Quality Assessment Method

Each article was evaluated based on criteria such as internal validity, topic relevance, research methods used, and the quality of the data presented. This process ensured that only high-quality articles served as the basis for the research analysis.

b. Data Extraction Method

The extracted data included:

1) The types and features of game labs developed, including the technologies used, target users, and learning objectives.
2) Gamification elements applied, such as points, rewards, leaderboards, and narrative elements.
3) Measured learning outcomes, including the impact on motivation, student engagement, and conceptual understanding.

This process was conducted manually and with the aid of analysis software to ensure the data produced was accurate and well-structured.

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c. Data Analysis Method

The data were analyzed qualitatively and quantitatively to identify patterns, trends, and relationships relevant to the study. Qualitative analysis was conducted to understand the context of gamification implementation and its impact within game labs, while quantitative analysis evaluated the effects of gamification on learning outcomes using metrics such as student participation rates, test scores, or time spent on learning activities.

The collected data were also compared across studies to identify gaps or inconsistencies and determine factors supporting the successful implementation of game labs. Additionally, the analysis results were mapped to observe the distribution of gamification usage based on geographic regions, educational levels, and subject areas involved.

This approach provides a holistic view of how game labs are developed and used, offering practical recommendations for educators and developers to adopt gamification in learning environments.

From the analysis of 34 articles, this study aims to provide in-depth insights into the trends in the development and application of game labs in education and their impact on student learning outcomes. The research also seeks to identify challenges in implementing gamification elements and provide recommendations for future research and practice.

3. RESULTS AND DISCUSSION

In recent years, research on the development and evaluation of game labs in educational contexts has advanced significantly. Game labs offer innovative solutions to challenges faced in conventional practices. Traditional laboratory practices are often constrained by expensive equipment and strict safety regulations, resulting in rigid and suboptimal learning processes. Game labs provide students with the opportunity to interact with equipment in a safe virtual environment, enhancing their understanding and skills before engaging in physical laboratory practices [7]. A review of existing studies reveals that researchers have developed various types of game labs to meet diverse educational needs.

3.1 Development of Game Labs

3.1.1 Science and Technology

Researchers have developed diverse types of game labs using various approaches to address learning needs across different fields. In science and technology, for example, a natural user interface (NUI)-based chemistry lab using motion sensors has been shown to increase student engagement in chemical experiments [8]. Additionally, an escape game titled "Carnivorous Yoghurts" was designed to help chemical engineering students understand mixing concepts while promoting independence in laboratory work [9]. In biology, an adventure-based game enables students to virtually practice using laboratory equipment without direct risks [7]. Other notable developments include "VR Cellverse," which allows students to explore cell structures and functions through collaboration between VR and tablet users, and "Geniverse," which enhances high school students' understanding of genetics through gamification [10][11]. A plant tissue culture game has also emerged as a distance learning alternative in bioengineering, offering students opportunities to enhance practical skills remotely [12]. Meanwhile, IVR-Honeybee provides immersive experiences for studying honeybee behavior [13]. Finally, virtual labs designed to improve accessibility and cost-efficiency in science and technology education show promise, though further development is needed for multidisciplinary applications [14].

3.1.2 Engineering

Significant progress has also been made in engineering-related game labs. Examples include "jAVANT-GARDE," a game designed to teach Java programming fundamentals, which has been shown to boost beginner students' confidence and motivation [15]. Another study developed a distributed lab for cybersecurity training, enabling students to practice critical skills for addressing cyber threats through simulations [16]. A gamified virtual control theory lab makes complex concepts easier to grasp through interactive simulations [17]. Game-based learning has also been applied in CAD courses to improve technical skills and encourage teamwork among mechanical engineering students [18]. Additionally, the adaptation of "Garry's Mod" as a laboratory training medium offers a safe and enjoyable learning experience for understanding basic mechanics [19]. Web-based simulations have also been used to introduce supply chain management concepts through hands-on experiences [20].

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In electronics and electrical engineering, researchers introduced a remote game-based lab that boosts student motivation using ranking systems and challenge-based scenarios [21]. Another study released a virtual lab simulation using immersive VR for electrical engineering training, enhancing both learning outcomes and motivation [22]. The "Talking Parrot" VR game, designed to teach basic electrical concepts, achieved a 91.7% improvement in student understanding, providing an engaging alternative to traditional paper-based methods [23]. Other game labs in electrical engineering incorporate gamified elements such as badges and leaderboards to facilitate progressive and focused learning [24].

3.1.3 Health Sciences

In health sciences, game labs are tailored to support clinical learning and skill development. For example, a digital game designed to teach arterial blood gas (ABG) principles improved students' ability to assess symptoms and make diagnoses [25]. VR applications for tracheostomy care training enhanced nursing students' practical skills [26], while 3D simulations like CareMe® improved clinical decision-making through virtual patient scenarios [27]. In pharmacy, escape rooms focused on parenteral drug administration training significantly enhanced students' practical skills [28], and diabetes-themed escape rooms deepened students' understanding of diabetes management [29].

3.1.4 Other Fields

Game labs have also been developed in other fields. Forensic training has benefited from VR games that simulate investigation procedures, from evidence collection to lab analysis, improving users' analytical skills [30]. For elementary school education, i-Vertex, a tangible technology-based game, helps children understand geometric concepts through interactive manipulation of smart objects [31].

3.2 Content Analysis of Game Labs

3.2.1 Health Sciences

Game labs in health sciences often incorporate content designed for interactive and practical learning. For example, medical-themed escape games challenge pharmacy students to solve puzzles related to diabetes management, offering practical and relevant learning experiences [29]. The Mini Educational Digital Game (MEDG) helps nursing students interpret ABG values in realistic clinical scenarios, bridging patient symptoms and appropriate treatments [25]. Escape rooms based on clinical scenarios also train students in parenteral drug administration through case-based challenges [28]. Additionally, CareMe® includes VR modules for clinical decision-making in virtual patient scenarios, strengthening nursing students' healthcare skills [27].

3.2.2 Sciences

In chemistry, games like Escape the Lab introduce interactive elements into experiments, helping students master laboratory skills such as using spectrophotometers and spectrometers in engaging escape room scenarios [32]. Carnivorous Yoghurts focuses on chemical engineering students' understanding of mixing processes and fosters independence through game-based challenges [9]. In biology, games like Serious Game enable students to interact virtually with lab equipment like microscopes through 3D simulations [7]. A plant tissue culture game teaches sterilization and micropropagation techniques using a safe and interactive approach [12]. Meanwhile, VR technology enhances the teaching of protein expression, offering a visual and immersive way to learn biology concepts [33].

3.2.3 Engineering

Engineering-focused game labs leverage gamification to increase learning motivation through elements like points systems, leaderboards, and badges [24]. jAVANT-GARDE offers engaging challenges for mastering Java programming basics [15]. Distributed labs for cybersecurity training integrate simulation scenarios to allow students to practice protecting infrastructures against real-world threats [16]. Virtual labs with instructional videos help students grasp technical concepts through interactive simulations, while 3D game-based design environments teach object-oriented programming in realistic simulations [34]. In electronics, LaboREM enables students to operate measuring tools and electronic circuits through remote simulations with game-based challenges [21]. Serious games based on VR train students to recognize hazards and manage risks in workplace safety scenarios [35].

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3.3 Impact of Game Labs on Learning

3.3.1 Health Sciences

Research shows that game labs incorporating gamification elements positively impact learning processes across various domains, ranging from improved conceptual understanding and learning motivation to enhanced practical skills. In the health field, several studies found that game labs with escape room concepts are particularly effective. For instance, in pharmaceutical education, escape rooms significantly increased students' knowledge of diabetes management, with post-test scores rising from an average of 56% to 81% [29]. In nursing, using escape rooms for teaching parenteral drug administration resulted in significant improvements in knowledge and clinical skills compared to traditional teaching methods. Additionally, virtual reality (VR)-based games for tracheostomy care training effectively enhanced technical skills such as tracheostomy tube suctioning and peristomal skin care, while also boosting students' learning motivation [36].

3.3.2 Chemistry Field

In chemistry, the integration of gamification technology with laboratory education has proven highly beneficial. Educational escape rooms used in chemistry labs enhanced students' understanding of stirring techniques and independence in experiments [9]. Augmented Reality (AR)-based escape rooms were also effective in increasing motivation and engagement among high school and university students. However, research indicates that desktop simulations yielded better learning outcomes than immersive VR, highlighting the importance of selecting appropriate learning mediums for game labs [32].

3.3.3 Engineering Field

In engineering education, simulation games and case-based games are utilized to help students grasp complex engineering concepts through interactive experiences. Research shows that these games improve students' conceptual understanding, engagement, and learning outcomes in engineering education [20]. One innovation is the adaptation of Garry's Mod as a virtual lab in mechanics, which increased students' confidence in using equipment and conducting virtual experiments before entering physical labs [19]. Similarly, VR training for laboratory safety demonstrated significant advantages, such as in studies involving pedestal grinder use, where VR-based training provided better comprehension of safety procedures than lectures or physical lab practice [37]. Gamification in programming education improved student engagement and motivation, leading to higher academic performance compared to traditional methods. In cybersecurity, game-based labs effectively taught students how to protect systems from cyber threats. Gamification elements like challenges and badges successfully enhanced students' intrinsic motivation [16].

3.3.4 Science and Technology (Saintek)

Game-based learning in science education has shown promising results. Game labs with 3D visualizations helped students understand laboratory procedures through engaging simulations, increasing both their engagement and comprehension [7]. For example, the VR-based game Cellverse was used to teach cell structure and function at the high school level. Positive user feedback improved scientific accuracy and user experience, demonstrating the game's ability to enhance students' understanding of cell structures and functions [10]. In science education, game-based learning has proven effective in improving students' understanding and engagement, with better outcomes compared to conventional teaching methods [11]. Additionally, in courses like Object-Oriented Analysis and Design (OOAD), the use of 3D games significantly improved students' comprehension and learning outcomes, offering an immersive and interactive learning experience [38].

3.3.5 Other Fields

Lastly, gamification in other fields, such as Microprocessors and Microcontrollers, has shown significant increases in students' interest and motivation. Studies found that gamification not only boosted student interest but also led to higher project and final grades compared to pre-gamification implementation [39]. A European-style board game called MOL (Mastering the Organic Chemistry Laboratory) was also effective in increasing students' interest and conceptual understanding in organic chemistry [40].

Overall, implementing game labs with gamification elements has proven successful across various fields of study. Game labs not only enhance conceptual understanding and practical skills but also foster motivation and engagement in learning. These findings align with constructivist theory, emphasizing the importance of active learning and interactive experiences. However, the effectiveness of game labs heavily

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depends on the design and medium of learning. For instance, desktop simulations were more effective than immersive VR in some cases, indicating that technological innovations must align with specific learning needs.

Critiques of this research include potential biases in study design, such as small sample sizes or limited generalizability to larger populations. Additionally, some findings suggest that while gamification boosts motivation, its impact on academic learning outcomes is not always significant. Therefore, further research is needed to explore factors influencing the effectiveness of game labs, including the role of personalized learning and individual differences among learners. Practical implications of this research include opportunities to integrate game-based learning more widely into educational institutions. This approach can provide dynamic and collaborative learning experiences, supporting continuous learning in the digital age.

4. CONCLUSION

This study concludes that game labs are an effective learning innovation across various disciplines. Game labs provide interactive, motivating, and safe learning experiences, especially for subjects requiring hands-on practice or complex visualizations. In the sciences, game labs support the understanding of abstract concepts through experiment simulations. Designed with gamification elements such as levels, points, and leaderboards, game labs enhance student engagement and motivation. The use of 3D visualizations and interactive interfaces enriches the learning experience, enabling students to gain a deeper understanding of the material. The research findings consistently show that game labs improve students' motivation, engagement, and learning outcomes across diverse fields of study.

Future research is recommended to evaluate the effectiveness of game labs at various educational levels using both quantitative and qualitative approaches to understand their long-term impact on student learning outcomes. The development of game labs with more immersive technologies, such as Virtual Reality (VR) and Augmented Reality (AR), should also be further explored to create deeper and more interactive learning experiences. Additionally, it is essential for developers to consider cultural diversity and local needs when designing game labs, ensuring the applications are more relevant to the users' contexts. This approach would enable game labs to be more broadly and effectively implemented across various disciplines and educational environments.

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