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Play to learn: innovating embryology education through a web-based gamification platform, and evaluating its effects on medical students' reaction, learning, and behavior

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Abstract

Background Embryology is often a challenging subject for medical students, leading to decreased engagement and learning difficulties. Gamification has gained attention as an innovative teaching method to enhance motivation and improve educational outcomes. This study examined the impact of gamified embryology education on medical students' reactions, learning achievements, and behaviors.

Methods A quasi-experimental study was conducted with 281 medical students at Jahrom University of Medical Sciences, Iran, from 2020 to 2022. Students in 2020–2021 received conventional instruction through online lectures and electronic content, while those in 2021–2022 were taught using the same routine methods supplemented by a gamification-based platform. Data collection tools included the 18-item Game User Experience Satisfaction Scale (GUESS), the 21-item Technology Acceptance Model (TAM) questionnaire, and a researcher-designed Quality of Online Learning Questionnaire (Q-OLQ). Final exam scores in embryology were compared between the groups. Statistical analysis was performed using SPSS version 21, employing descriptive statistics and Independent Samples t-tests to assess differences in academic performance.

Results All questionnaire components scored above the threshold, indicating positive responses. The highest satisfaction scores were found in Enjoyment (3.98 ± 1.02) and Visual Aesthetics (3.92 ± 1.04). For technology acceptance, Perceived Usefulness (4.06 ± 0.88), Concentration (3.96 ± 0.83), and Attitude towards Using (3.95 ± 0.90) were rated highly. Regarding online learning quality, Quality of Online Resources (3.95 ± 0.97) and Perceived Importance of Online Resources (3.90 ± 0.99) received the top scores. Importantly, students who experienced gamification alongside routine teaching scored significantly higher on final exams ($p < 0.001$).

Conclusions The findings indicate that gamification effectively enhances student engagement and learning outcomes in medical education, suggesting its valuable role as a complementary teaching strategy.

Keywords Game, Medical education, E-Learning, Embryology, Educational technology, Kirkpatrick model

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Introduction

Embryology, a fundamental subject in medical education, often presents significant challenges for students due to its complexity, abstract concepts, and the requirement for spatial visualization of developmental processes [1, 2]. Traditional teaching methods, such as lectures and textbook study, may not fully engage students or foster deep understanding and long-term retention of the material [3]. Consequently, educators have sought innovative strategies to enhance learning experiences, improve problem-solving skills, and positively influence student behaviors. One promising approach is the integration of gamification into embryology education.

Gamification refers to the application of game design elements—such as points, badges, leaderboards, challenges, and interactive storytelling—into non-game contexts to motivate users and increase engagement [4, 5]. In medical education, gamification aims to transform passive learning into an active, enjoyable, and competitive experience, thereby enhancing motivation, knowledge acquisition, and critical thinking [6, 7]. The use of gamified platforms in teaching complex subjects like embryology has gained momentum, as it aligns with the learning preferences of modern students, who are digital natives accustomed to interactive technologies.

Several studies have demonstrated the potential benefits of gamification in medical education [8–12]. For example, a systematic review by Gentry et al. [11] highlighted that gamified learning can improve knowledge retention, learner engagement, and satisfaction across various medical disciplines. Specifically, in anatomy, histology, and embryology, gamification has been shown to facilitate spatial understanding and promote active recall, which are critical for mastering developmental biology [13, 14]. Moreover, gamified learning environments encourage collaborative learning and healthy competition, which can enhance problem-solving skills and foster positive behavioral changes, such as increased persistence and self-directed learning [15].

Despite these promising findings, the impact of gamification on medical students' problem-solving abilities and behaviors in embryology remains underexplored. Problem-solving is a core competency for medical professionals, involving the application of knowledge to effectively diagnose and manage clinical scenarios. Embryology, with its intricate developmental pathways, provides an excellent platform to develop such skills when taught through engaging and interactive methods. Furthermore, behavioral outcomes such as motivation, participation, and attitudes towards learning are important indicators of the effectiveness of educational interventions and can influence long-term academic success [13, 16].

The application of gamification in medical education is grounded in established theoretical frameworks, such

as Experiential Learning Theory (ELT) and Self-Determination Theory (SDT). According to Kolb's ELT [17], learning is most effective when it follows an active, cyclical process consisting of four stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation [10, 17]. This model emphasizes that learners acquire knowledge by engaging directly in experiences, reflecting on them, developing new concepts, and then applying these concepts practically. Gamified educational settings align well with this theory by involving students in interactive tasks that simulate real-world challenges, thereby enhancing deeper learning and retention [18].

In parallel, Self-Determination Theory (SDT) provides a framework for understanding motivation within gamified learning environments. SDT emphasizes the fulfillment of three fundamental psychological needs—autonomy, competence, and relatedness—as essential for fostering intrinsic motivation and engagement [19, 20]. Gamification elements such as goal setting, learner autonomy, and timely feedback can be intentionally designed to satisfy these needs. For example, enabling students to select their learning paths (autonomy), providing opportunities to demonstrate mastery (competence), and promoting collaboration (relatedness) contribute to improved motivation and educational outcomes [20, 21]. When gamification adheres to these principles, it encourages learners toward higher intrinsic motivation and sustained engagement [21]. This study aims to innovate embryology education by implementing a gamified, web-based learning platform tailored for medical students during the COVID-19 pandemic.

The COVID-19 pandemic has accelerated the shift toward modern technologies in education, highlighting the need for innovative approaches to enhance learners' performance and experiences. In medical education, particularly in embryology, understanding anatomical development and congenital disorders is crucial [22]. Advances in prenatal ultrasonography and the management of congenital anomalies have further underscored the importance of embryology in the 21st century. However, many institutions still rely on traditional teaching methods. The integration of technology and active learning strategies, such as gamification, holds significant potential to transform medical education, especially in complex subjects like embryology. Implementing new technologies in diverse educational contexts requires careful exploration to understand their impact on learning experiences. While developed nations increasingly adopt these technologies, their application in developing countries demands thoughtful design and evaluation due to their novelty. Gamification in embryology education can facilitate active learning, making it a promising approach.

Nevertheless, it is necessary to examine the effects of applying educational innovations and elements of gamification on different dimensions of teaching and learning, and to obtain solid evidence to determine the effectiveness of these methods. One of the most common and valid models is the Kirkpatrick method [23, 24].

The Kirkpatrick model was selected because it provides a comprehensive framework for evaluating educational interventions at multiple levels, from learners' immediate reactions to changes in behavior and performance. This model is particularly suited to medical education, where both knowledge acquisition and behavioral application are critical. By assessing outcomes at reaction, learning, and behavior levels, it ensures a holistic understanding of the intervention's effectiveness beyond short-term knowledge gains.

Based on Kirkpatrick's evaluation model, the aim of the present study, is to examine the impact of using gamification on the satisfaction, learning, and performance of medical students in the Embryology course.

Methods

Study design

This quasi-experimental study was conducted to design, implement, and evaluate a gamified approach for teaching embryology within the "Basics of Anatomical Sciences" course at Jahrom University of Medical Sciences, Jahrom, Iran.

Participants and sampling

The study involved a sample of 281 first-year medical students who took the embryology course during the COVID-19 pandemic, spanning three academic years from 2020 to 2022.

From 2020 to 2022, the courses were delivered online synchronously using Adobe Connect software. Additionally, following a Flex e-Blended learning approach, electronic course materials were uploaded to the learning management system, allowing students to access the content asynchronously.

Starting in 2021, a web-based gamification platform was developed for the embryology course. Students enrolled in 2022 used this platform alongside routine teaching methods.

Between October 2020 and July 2021, 143 medical students enrolled in the embryology course and used the routine online method; their data were recorded in the system. From October 2021 to July 2022, 138 students used the gamification platform in addition to the routine method.

Since the course is offered in the first semester, all participants entered the program without prior experience in virtual education. The study was conducted independently of any other virtual training initiatives. Inclusion

criteria required active enrollment in the "Basics of Anatomical Sciences" course, while exclusion criteria involved failure to complete the questionnaires.

To develop the educational content and framework, a collaborative team was formed, consisting of two embryologists, a medical education specialist, and a technical expert responsible for designing and developing the gamified elements.

Educational design

Traditional group In the routine group, who received traditional instruction, the professor's lectures with PowerPoint or other format were delivered online simultaneously via Adobe Connect software. In addition, supporting electronic content was uploaded on the university's learning management system called NAVID. This LMS provided features such as assignment submission, self-assessment quizzes, uploading electronic content, and communication between the professor and students. The topics covered included "gametogenesis," "ovulation to implantation," "development of the body cavities," "embryonic period," "placenta and fetus," and "congenital anomalies." Visual aids, such as images, were incorporated into the questions to enhance engagement and understanding while adhering to educational standards.

Gamification group In the gamification group, in addition to the routine methods, a web-based gamification platform was used. The educational content for the gamification was structured into two primary components: course knowledge and concepts. This was delivered through various question formats, including multiple-choice questions, matching questions, and fill-in-the-blank items. The educational content and topics were the same for both groups.

The gamified teaching method was designed around the principal concepts of the course, utilizing the *Octalysis Framework* [5] to create a simulated learning environment. Various sets of questions were developed, varying in number from 5 to 15. Each question was timed, with a limit of 30 s to encourage quick thinking and decision making. The integration of scientific gamification based on constructivist theories aims to foster knowledge development within a game-based environment, promoting deep and effective learning. Key elements such as immediate feedback, challenges, competition, and an engaging multimedia environment were incorporated to motivate students and enhance their educational experience (Fig. 1).

The gamification platform presented students with a series of challenges, with progression contingent upon achieving a specified score in each section. Specifically, students were required to attain at least 75% of the total score for each step to advance to the next level.

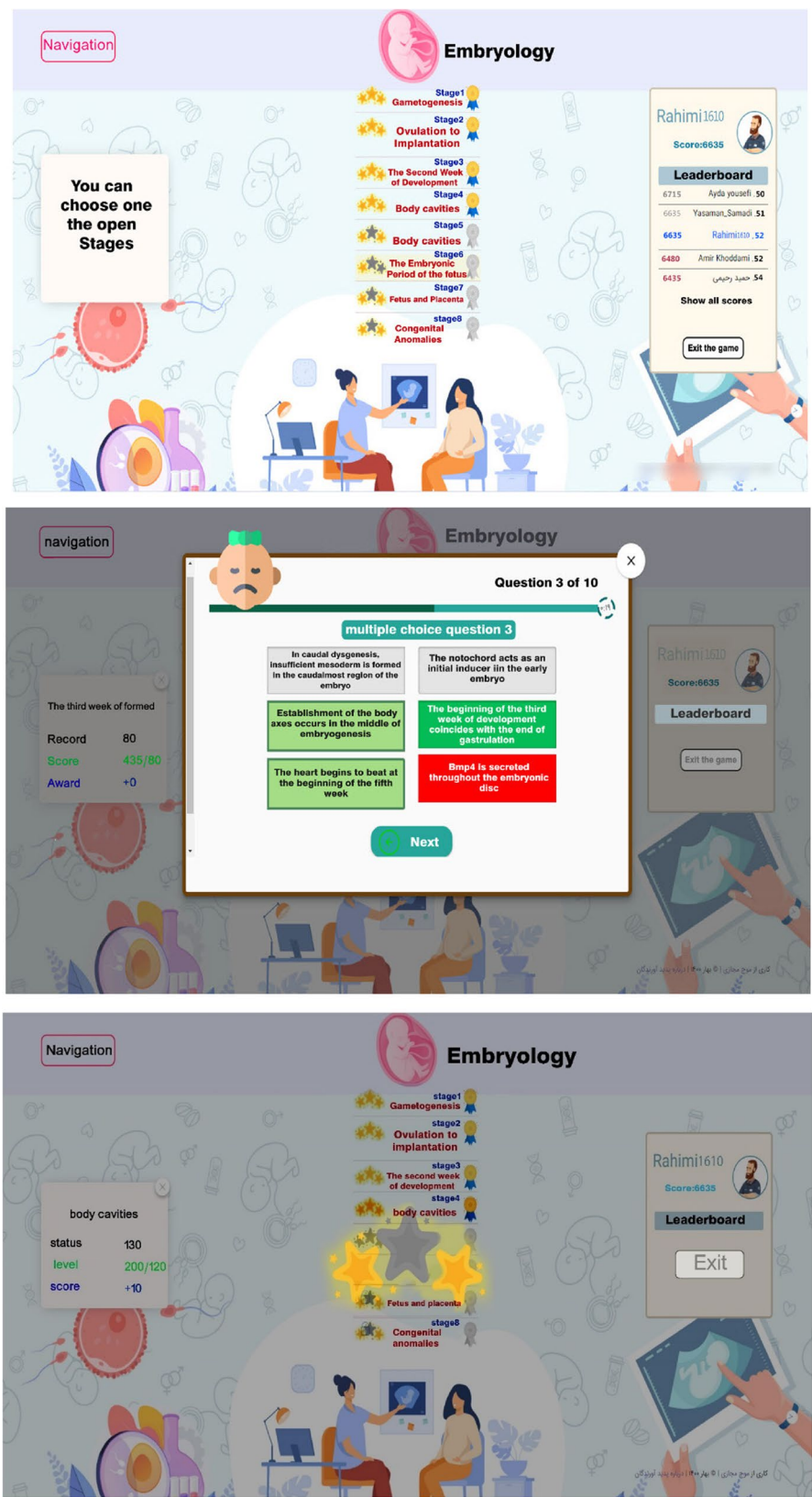


Fig. 1 gamification process and contents **A** the game leaderboard and its levels **B** a sample of multi-choice questions and their answers, with feedback provided on the wrong answer, & **C** rewarding situation in the game

The gamification platform and its educational content and quizzes were presented in English, which is the official language of the course materials and the primary reference textbook for embryology. All participants had previously passed the English for Specific Purposes (ESP) course, ensuring proficiency in understanding the specialized English terminology used in the platform.

Technical design

The technical design phase focused on creating a user-friendly and engaging game environment. Features were integrated to enhance the game's attractiveness, efficiency, and educational purpose. These included customizable game elements for users, monitoring capabilities for professors, achievement badges, limitations, challenges, leaderboards, and avatars. The leaderboard facilitated tracking of individual and group performance, allowing students to see their progress and standings in real-time (Fig. 1).

Technical characteristics of platform The gamification platform (<https://emberio.ir/>) was a custom-designed, web-based application developed specifically for this study by a collaboration between medical education experts, embryology faculty members, and a professional software development team. The system was built using HTML5, CSS3, JavaScript (React framework), and PHP for backend processes, supported by a MySQL database. The platform was hosted on a secure server with SSL encryption. This custom design allowed full flexibility to incorporate course-specific content, integrate various game mechanics (leaderboards, badges, timed challenges, and progression levels), and track detailed user engagement data. The custom approach ensured alignment with the course objectives, controlled timing of questions, and inclusion of multimedia embryology resources.

Before classroom implementation, the main application underwent rigorous testing by both technical experts and students to identify and rectify any bugs or issues, ensuring a smooth user experience in the educational setting.

Tools/instrument

Evaluation of the program was conducted at the first three levels of the Kirkpatrick model. To ensure accurate and comprehensive responses in the evaluation phase, all questionnaires (GUESS, TAM, and Q-OLQ) were administered in Farsi, the students' native language.

Reaction level

Focusing on reaction, learning, and behavior. Two primary questionnaires were employed to assess the program's effectiveness at the reaction level.

1. *Game User Experience Satisfaction Scale (GUESS)*: This satisfaction questionnaire comprised 18

items across nine domains (usability/playability, narratives, efforts, creative freedom, enjoyment, personal gratification, social connectivity, visual aesthetics, and audio aesthetics). Each domain included two items [25] rated on a Five-point Likert scale, ranging from "completely agree = 5" to "completely disagree = 1" (Cut-off-Point = 3). The GUESS-18 is a condensed 18-item version of the original 55-item GUESS scale, which was developed and psychometrically validated by Phan et al. in 2016. This shorter scale is designed to evaluate various types of video games and can also be used to support interviews or discussions with users about their gaming experiences. The point that must be mentioned about the GUESS questionnaire is that, although these domains include only two items, previous validation studies have demonstrated that two well-constructed items can reliably capture the construct, particularly when each item represents a distinct but complementary aspect of the domain. Furthermore, reliability analysis in the current study confirmed acceptable internal consistency for these domains.

2. *Game Acceptance questionnaire*: This instrument, adapted from the Technology Acceptance Model (TAM) questionnaire, consisted of 21 items across seven domains: perceived ease of use, perceived usefulness, perceived pleasure, perceived control, concentration, attitude toward use, and behavioral intention. Each domain contained three items, rated on a five-point Likert scale from 1 to 5 and Cut-off-Point = 3 [26].
3. *Quality of Online Learning Questionnaire (Q-OLQ)*: students' self-reported perceptions of the course quality were assessed using a researcher-made questionnaire. For this purpose, the Quality of Online Learning Questionnaire (Q-OLQ) was used, which was developed by the research team. This questionnaire consists of 19 items across 6 main components, using a 5-point Likert scale. The components are: Perceived Importance of Online Resources – 3 items; Accessibility and Convenience of Resources – 3 items; Use of Online Resources for Study Planning and Preparation – 2 items; Integration and Quality of Online Resources – 2 items; Motivation and Study Behavior – 4 items; and Social Influence on Learning – 5 items. The content validity of this instrument was confirmed using the opinions of 10 educational experts with a Content Validity Index (CVI) of 85%, and its reliability was confirmed with 40 samples using Cronbach's alpha, which was above 80%.

Learning level:

1. To assess the second level of the Kirkpatrick model (Learning), the final exam scores of medical students in the embryology course who participated in the gamified approach were compared to those of students from different semesters who received traditional instruction. The score range is from 0 to 20, and the minimum passing score is 12. Scores between 12 and 17 are considered average, while scores between 17 and 20 indicate proficiency.

Behavior level:

2. At the third level of the Kirkpatrick Model, relevant outcomes such as time spent, exercise, and use of the game app were examined. This aligns with Level 3 of the Kirkpatrick Model, which evaluates whether participants apply what they have learned by observing behavioral changes like engagement in activities and use of tools or apps. The system also allowed for the awarding of extra points to students who excelled in the game.

Data analysis

Statistical analysis was performed using SPSS version 21 software. Descriptive statistics, including the calculation of mean and standard deviation, were employed to analyze the study results. Additionally, Independent Samples t-Test was utilized to compare the scores of students between the experimental (gamification) and traditional teaching groups, providing insights into the effectiveness of the gamified learning approach.

Results

Of the 138 students enrolled in the gamification group who had selected the course “Basics of Anatomical Sciences,” 16 did not complete all three questionnaires, leaving 122 eligible participants. Demographic analysis showed that 51.4% were female and 48.6% were male with an average age of 19 years (± 1.34). (Fig. 2)

Statistical finding

The effectiveness of the program was evaluated according to the three phases of the Kirkpatrick model. This involved assessing participants’ reactions, measuring learning outcomes, and examining behavioral changes resulting from the training.

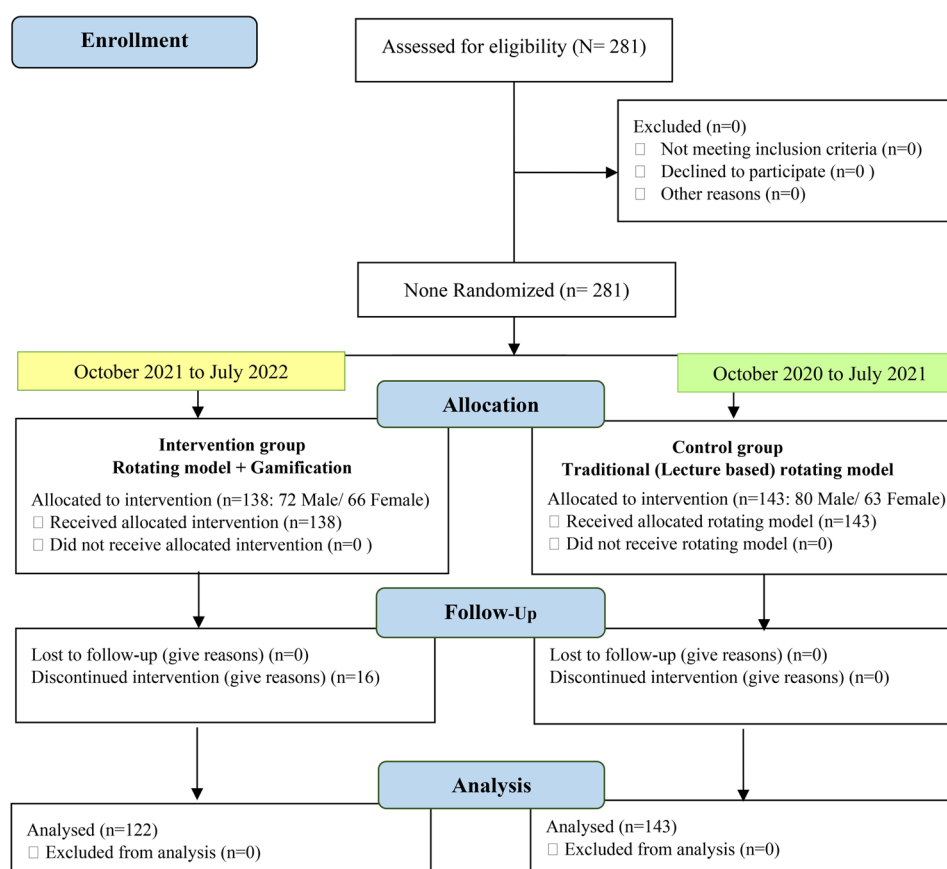


Fig. 2 CONSORT flowchart and participant assignment to intervention and control groups

Table 1 Students' satisfaction from gamification teaching based on GUESS questionnaire

GUESS (Game user experience satisfaction scale)	Mean $\pm$ (SD)
Domain/Item	
Usability (Playability)	3.48 (1.45)
o I find the controls of the game to be straightforward.	3.82 (1.73)
o I find the game's interface to be easy to navigate.	3.13 (1.16)
Narratives	3.76 (1.72)
o I am captivated by the game's story from the beginning.	3.71 (1.62)
o I enjoy the fantasy or story provided by the game.	3.80 (1.81)
Play engrossment	3.18 (1.64)
o I feel detached from the outside world while playing the game.	3.26 (1.70)
o I do not care to check events that are happening in the real world during the game.	3.10 (1.58)
Enjoyment	3.98 (1.02)
o I think the game is fun.	3.90 (1.03)
o I feel bored while playing the game (reverse code).	4.05 (1.02)
Creative freedom	3.14 (1.76)
o I feel the game allows me to be imaginative.	3.24 (1.78)
o I feel creative while playing the game.	3.04 (1.73)
Audio aesthetics	3.07 (1.82)
o I enjoy the sound effects in the game.	3.14 (1.83)
o I feel the game's audio (e.g., sound effects, music) enhances my gaming experience.	3.00 (1.80)
Personal gratification	3.11 (1.68)
o I am very focused on my own performance while playing the game.	2.81 (1.71)
o I want to do as well as possible during the game.	3.41 (1.65)
Social connectivity	3.55 (1.20)
o I find the game supports social interaction (e.g., chat) between players.	3.45 (1.25)
o I like to play this game with other players.	3.65 (1.14)
Visual aesthetics	3.92 (1.04)
o I enjoy the game's graphics.	3.87 (1.09)
o I think the game is visually appealing.	3.96 (0.99)
Total	3.47 (1.48)

SD Standard Deviation Cut-off-Point = 3

Finding of reaction level

The findings from the measurement of the reaction level were initially assessed using the GUESS questionnaire to evaluate students' satisfaction with various aspects of game-based learning (gamification) (see Table 1). Based on the findings of Table 1, the highest mean scores belong to the components Enjoyment (3.98 ± 1.02) and Visual aesthetics (3.92 ± 1.04), and in all components, the scores are above the cutoff point.

Furthermore, students' levels of technology acceptance were assessed, and the findings are summarized in Table 2. The data show that acceptance in multiple domains was mostly above average (Table 2). Based on the findings of Table 2, the highest mean scores belong to the components Perceived usefulness (4.06 ± 0.88), Concentration (3.96 ± 0.83), and Attitude towards using

Table 2 Mean of all items in learning from game acceptance based on TAM questionnaire

Game Acceptance	Mean $\pm$ (SD)
Domains/items	
Perceived ease of use	3.89 (1.02)
o It is easy for me to become skillful at playing the game.	3.70 (1.14)
o I think that the game is easy to play.	3.92 (0.96)
o Learning to play the game is easy for me.	4.04 (0.95)
Perceived usefulness	4.06 (0.88)
o I think that the game is useful in assisting me with learning.	4.12 (0.88)
o I think that the game is useful in assisting me with learning in a quick fashion.	3.87 (0.79)
o I can achieve greater learning effectiveness with the assistance of this game.	4.20 (0.96)
Perceived enjoyment	3.34 (1.10)
o I have full control over the proceedings of the game.	3.66 (1.08)
o I sense no confusion when playing the game.	3.58 (1.18)
o I feel no frustration when playing the game.	3.78 (1.03)
Perceived control	3.68 (0.93)
o I have full control over the proceedings of the game.	3.64 (0.87)
o I sense no confusion when playing the game.	3.64 (0.97)
o I feel no frustration when playing the game.	3.75 (0.96)
Concentration	3.96 (0.83)
o I am completely engrossed in the game when playing it.	3.93 (0.80)
o I pay full attention to the game when playing it.	4.00 (0.83)
o I concentrate solely on the game when playing it.	3.94 (0.86)
Attitude towards using	3.95 (0.90)
o I regard playing the game as a good idea.	4.06 (0.90)
o I find that the game makes vocabulary learning more interesting.	3.95 (0.95)
o I prefer learning English vocabulary by using the game.	3.86 (0.85)
Behavioral intention	3.52 (1.09)
o I am willing to play the game frequently.	3.56 (1.14)
o I am willing to recommend others to play the game.	3.70 (1.04)
o I am willing to repeatedly playing the game in the future.	3.29 (1.10)
Total	3.76 (0.96)

SD Standard Deviation Cut-off-Point = 3

(3.95 ± 0.90), and in all components, the scores are above the cutoff point.

Also, the quality of online learning was examined using the Q-OLQ questionnaire, and the mean scores of the items and components are presented in Table 3. Based on the findings of Table 3, the highest mean scores belong to the components Quality of Online Resources (3.95 ± 0.97) and Perceived Importance of Online Resources (3.90 ± 0.99). Additionally, the scores for all components are above the cutoff point.

Finding of learning level

To assess student learning, the final exam scores of the students in the Embryology course were used as the criterion. Additionally, the final exam scores of students who took the same course last year using the routine method

Table 3 Mean of all items in quality of online learning based on Q-OLQ questionnaire

Quality of online learning Components/items	Mean $\pm$ (SD)
Perceived Importance of Online Resources	3.90 (0.99)
o I find the audio-visual online resources provided by our teachers crucial for my learning.	4.23 (0.93)
o I find external audio-visual online resources very important to my learning.	4.01 (1.02)
o Specific external online resources are vital to my independent learning.	3.45 (1.06)
Accessibility and Convenience	3.72 (1.02)
o Accessibility to teachers' lectures online enhances my independent learning.	4.21 (1.06)
o I learn more efficiently when I'm able to access online resources using different devices.	2.98 (1.13)
o Access to online material off-campus enables me to structure my independent learning.	3.97 (0.86)
Study Planning and Preparation	3.34 (1.33)
o I use recorded lecture material as a guide for what to learn.	3.63 (1.53)
o I seek online resources to prepare my learning materials before a learning activity	3.05 (1.12)
Quality of Online Resources	3.95 (0.97)
o Some online resources are efficient because they are well summarized.	4.02 (0.96)
o I often use a variety of teachers' content and other online resources to support my learning.	4.02 (0.96)
Motivation and Study Behavior	3.48 (0.88)
o Flexibility to use a variety of online material motivates my independent learning.	3.25 (1.02)
o Having available online resources increases my motivation to succeed in the exam	2.87 (0.85)
o My motivation to study increases leading up to exams.	4.36 (0.67)
o I set up study goals that organize/structure my learning.	3.45 (0.99)
Social Influence on Learning	3.57 (0.96)
o My study is stimulated by group discussions.	3.21 (0.88)
o My study habits are influenced by my peers/social interaction.	3.87 (0.93)
o My study is influenced by the fact that I need to maintain my Academic credibility	2.67 (1.24)
o I find small group work enhances my understanding about a particular concept.	3.81 (0.94)
o I am able to consolidate my learning following a small group activity.	4.29 (0.81)
Total	3.83 (1.03)

Table 4 Mean scores of students in two groups

Groups	N	Mean	SD	t	p
• Gamification	122	17.32	0.99	8.79	< 0.001
• Traditional	143	15.68	1.02		

Minimum passing score = 12. Moderate level: score > 12–17 Mastery level: score > 17–20

SD Standard Deviation Score range: 0–20

Table 5 Some finding extracted from students' performance in gamification platform

Indicator	Performance
Student engagement	Out of 138 students, 130 had registered on the system, but 122 students accessed the platform modules and successfully earned points.
Time spent and achievements	o The duration of students' presence on the platform ranged from 90 min to 380 min over the course of one academic semester. o The content rooms included 5 to 15 questions with scores ranging from 200 to 635, and the total score for the hall was 4,105, which could be achieved within 100 s. o The score table showed students' scores ranging from 760 to 11,000, with 78 students achieving scores above 4,100 by repeating specific content. o In the management platform, the average score for students who played for at least 120 s was 5,880, and the average completion time was 90 s for non-repetitive gameplay. o Students focused on improving their scores, earning badges, and collecting stars, which enhanced content retention and performance. o Students earned 21 stars by correctly answering one-third of the questions in each content section. They could track their scores and improve through practice. o Top students answered 95% of the questions correctly and received medals for their intelligence, knowledge, expertise, and mastery. o The top one-third of students received badges based on their average scores.

(online lectures by the instructor along with electronic content files uploaded on the LMS) were also compared (Table 4).

As shown in Table 4, the scores of both groups are above the passing score; however, the scores of the group that used the gamification method in addition to the routine method were significantly higher ($p < 0.001$).

Finding of behavior level

After the completion of the course, some performance indicators of the students on the web-based gamification platform for the Embryology course were examined. The reports from this system are presented in Table 5. Overall, by reviewing and analyzing the obtained results alongside the students' scores, the findings showed that students who used the platform more extensively and earned higher scores on it also achieved better scores in the final exam.

Discussion

The present study evaluated the impact of a gamified web-based platform on medical students' satisfaction, learning outcomes, and behavioral changes in an embryology course, using the Kirkpatrick model as a guiding framework. The findings provide compelling evidence

that integrating gamification into medical education can enhance student engagement, perceived learning quality, and academic achievement.

Game user experience satisfaction

The present study's findings align with a growing body of evidence supporting gamification as an effective pedagogical tool that enhances student engagement and satisfaction. Notably, the high scores in enjoyment and visual aesthetics reflect the intrinsic motivational benefits of gamified learning environments, which have consistently been shown to increase learner engagement and improve educational outcomes [18, 19]26– [30]. These results underscore the importance of designing gamified experiences that are both enjoyable and visually appealing to maximize student involvement [27–30].

Furthermore, the positive ratings in the narrative domain suggest that incorporating storytelling elements within gamification can deepen engagement by providing meaningful contexts and fostering emotional connections to the learning material [31, 32]. This observation is supported by previous research reporting that narrative-driven gamification enhances both motivation and learning persistence, highlighting the value of immersive storylines in educational games [28].

In addition to enjoyment and narrative engagement, the moderate to high scores in usability and social connectivity indicate that students found the gamified platform accessible and appreciated its social interaction features. This finding is consistent with Hamari et al. [7], who emphasized that ease of use and social components are critical factors for the successful adoption and sustained use of gamified systems. The social dimension of gamification not only promotes collaboration but also contributes to a sense of community among learners, further enhancing satisfaction and motivation.

Despite these positive outcomes, the study identified areas for improvement. Lower scores in audio aesthetics and creative freedom suggest that while visual elements were well-received, the auditory design and opportunities for creative expression were less satisfying. Mekler et al. [33] similarly noted that sensory elements such as sound significantly influence user experience but are often underutilized in educational games, indicating a potential avenue for enhancing engagement through richer audio design. Additionally, the modest score in personal gratification points to the need for more personalized feedback and goal-setting features, which have been shown to bolster motivation and performance in gamified learning environments [27–30, 34]. Subhash and Cudney [35] reported that gamification positively affects learner engagement and satisfaction, particularly when creative freedom is supported, echoing the current study's findings. Moreover, social connectivity features in

gamified learning environments promote collaboration and satisfaction, resonating with the social connectivity scores observed here [36].

Gamification acceptance

This study reveals a generally positive acceptance of gamified learning tools, particularly highlighting perceived usefulness and ease of use as key factors driving adoption, consistent with the Technology Acceptance Model [37]. Students acknowledged the game's effectiveness in facilitating vocabulary learning, aligning with previous research demonstrating gamification's role in enhancing educational outcomes [37]. Similarly, a study by Mosalanejad and colleagues on a web-based gamification platform for medical students teaching psychological topics reported high scores across all components of the TAM [26, 37].

High scores in concentration and attitude towards using indicate strong engagement and favorable perceptions, which are essential for sustained use and successful learning [7, 26, 37]. These findings support the notion that gamified environments enhance motivation by making learning more interactive and enjoyable.

Quality of online learning: students

Generally perceive online learning as effective and valuable, with an overall positive rating. They particularly emphasize the importance of audio-visual resources, especially those created by instructors, which aligns with research highlighting multimedia's role in improving comprehension and retention [38]. The availability of diverse, well-summarized content further supports effective learning, consistent with findings that quality resources are key drivers of online success [39, 40].

Accessibility and convenience are also highly valued, particularly off-campus access that supports flexible and independent study [40, 41]. However, lower scores for multi-device access suggest technical or usability challenges common in online education, indicating a need for improved platform compatibility.

Regarding motivation and study behavior, students' motivation peaks near exam periods, reflecting the strong influence of assessment deadlines [42]. Yet, moderate motivation derived from resource flexibility suggests that merely providing materials is insufficient to sustain engagement, underscoring the importance of interactive and engaging online designs [43]. Social influences such as group discussions and peer interaction are moderately valued, with small group work enhancing understanding and learning consolidation. This highlights the role of social presence and collaboration in online learning environments [44, 45]. The relatively low impact of academic credibility on study habits may reflect individual differences or the nature of online learning.

Lower scores in study planning and preparation suggest that students may not consistently use online resources proactively, echoing research on the critical yet often underdeveloped role of self-regulated learning skills in online settings. Encouraging better planning could improve learning outcomes. Considering that the participants in this study were first-year medical students, it is possible that their self-management and self-regulation skills have not yet matured, emphasizing the need to provide appropriate training in these areas.

Enhancing learning outcomes

The significantly higher academic scores observed among students exposed to gamified teaching methods demonstrate that gamification is more effective than traditional approaches in improving learning outcomes. This finding aligns with an expanding body of evidence showing that gamification enhances motivation, engagement, knowledge retention, and cognition, thereby fostering superior academic performance [27–31, 45, 46].

Gamification promotes active learning by integrating game elements such as immediate feedback, challenges, and rewards, which boost intrinsic motivation and encourage deeper cognitive processing [7, 47]. The mastery-level achievements among gamified learners highlight the potential of these strategies to move students beyond basic understanding toward higher-order thinking skills.

Behavior

Gamification effectively promotes high student engagement and motivation, as evidenced by strong participation and registration rates. The use of rewards such as points, badges, and stars aligns with Self-Determination Theory, which suggests that these elements satisfy psychological needs for competence and relatedness, thereby enhancing intrinsic motivation [5]. The ability for students to track their progress and receive recognition fosters sustained engagement and encourages repeated practice, essential for deep and lasting learning [7].

The platform's efficient content delivery enables students to achieve high scores within relatively short timeframes, facilitating mastery through repetition. This repeated engagement reflects the principles of deliberate practice, which are critical for skill acquisition and knowledge retention [48]. Recognition mechanisms, such as medals and badges awarded to top performers, create a positive feedback loop that motivates students to strive for mastery. Research supports that such gamified rewards increase learner persistence and academic achievement [5, 33, 49].

Overall, the study demonstrates that gamification significantly enhances student engagement, motivation, and learning outcomes by creating enjoyable, visually

appealing, and interactive educational experiences. Incorporating storytelling

Limitation and suggestions

Limitations

Despite the promising results of this study, several limitations should be considered when interpreting the findings. The research was conducted at a single medical university, which may limit the generalizability of the results to other institutions or educational settings with different resources, student demographics, or teaching cultures. Of the 138 students enrolled in the gamification group, only 122 completed all phases of the study, raising the possibility of self-selection and attrition bias. Students who were more motivated or interested in gamified learning may have been more likely to participate fully, potentially skewing the results. Additionally, the study primarily assessed immediate reactions, learning outcomes, and behavioral changes; long-term retention of knowledge, transfer of skills to clinical practice, and sustained behavioral changes were not evaluated. Many outcome measures, such as satisfaction, technology acceptance, and behavioral intentions, relied on self-reported questionnaires, which are subject to biases including social desirability and recall bias.

Suggestions for future research

Future studies should be conducted across multiple institutions and include more diverse student populations to enhance external validity and applicability of findings. Incorporating long-term follow-up assessments can provide insights into the durability of learning gains, impacts on clinical performance, and sustainability of behavioral changes. Exploring a wider range of gamification elements—including adaptive difficulty, immersive storytelling, and collaborative multiplayer features—could offer a more comprehensive understanding of what drives engagement and learning. Combining quantitative surveys with qualitative methods such as interviews or focus groups would yield richer insights into students' experiences, preferences, and perceived barriers or facilitators. Where possible, self-reported data should be supplemented with objective measures of engagement and performance, such as platform usage analytics, time-on-task, and direct observation.

Conclusion

This study highlights the significant benefits of incorporating gamification into embryology education for medical students. The gamified learning platform not only enhanced students' satisfaction and engagement but also led to improved learning outcomes and positive behavioral changes. By fostering an interactive and motivating learning environment, gamification facilitated a better

understanding of complex embryological concepts and encouraged active participation and collaboration among students.

While the findings are promising, further research involving diverse educational settings and long-term follow-up is necessary to fully establish the sustained impact of gamified education on knowledge retention and clinical application. Overall, this study supports the integration of gamification as an effective educational strategy to innovate medical curricula and enhance student learning experiences.

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Authors' contributions

MR contributed to writing the primary draft, reviewing and editing, investigation, project administration, and conceptualization; RH was involved in investigation and conceptualization; LM participated in editing the original draft, methodology development, conceptualization, and software design; ZK designed and validated the instrument, analyzed and visualized the data, and wrote the final manuscript. All authors approved the final version of the manuscript.

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Data availability

Yes, the datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Student information was used confidentially, and the necessary permissions to access student data on the platforms were obtained from the Deputy of Education and Research. Students were fully informed about the objectives of the study and participated voluntarily with informed consent. The study was approved by the Ethics Committee at Jahrom University of Medical Sciences with approval number IRJUMS.REC.1402.006. Written informed consent was obtained from all participants.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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