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Original Article

The Effectiveness of Gamification-Based Microlearning on Cognitive Load in Histology Education Among Biology Students: A Quasi-Experimental Study

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ABSTRACT

Background: While gamification is increasingly used in higher education, its impact on the specific dimensions of cognitive load particularly in complex subjects like histology remains underexplored. This study aimed to investigate the effect of gamification-based microlearning on students' overall cognitive load in histology, with a specific interest in its potential differential impact on extraneous and germane cognitive load.

Methods: This quasi-experimental study employed a pretest-posttest design with a control group. The sample consisted of 27 undergraduate biology students from Arak University, enrolled between January and June 2024, who were randomly allocated to either an experimental group (n=14) or a control group (n=13). Participants in the experimental group were taught histology using a specially developed gamified microlearning application over a 14-week period, whereas the control group received conventional lecture-based instruction. Cognitive load was assessed using the Paas Cognitive Load Scale, and the primary outcome was evaluated through a change score analysis. All statistical analyses were performed using IBM SPSS Statistics, version 23.

Results: Analysis of change scores indicated a substantial difference between groups. The experimental group demonstrated a significant decrease in cognitive load (Mean=−7.71, SD=2.76), while the control group experienced a modest increase over time (Mean=2.31, SD=5.11). An independent-samples t-test indicated that the difference in change scores between the two groups was statistically significant (P<0.001). Furthermore, the effect size was exceptionally large (Cohen's d=2.47).

Conclusion: Gamified microlearning appears to be an effective instructional approach for reducing cognitive load in complex scientific subjects. The results indicate that this integrated method may enhance the efficient use of cognitive resources. Future studies should include larger sample sizes, distinguish among different types of cognitive load, and investigate long-term outcomes as well as applicability across various disciplines.

Keywords: Biology, Education, Cognitive Load, Gamification, Histology, Microlearning

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Introduction

Higher education, as one of the fundamental pillars of sustainable development, plays an unparalleled role in training specialized human resources and advancing the frontiers of knowledge and technology (1). In the present era, universities are expected to shift toward entrepreneurial and innovative models (third- and fourth-generation) whose mission is to address complex societal problems and cultivate creative individuals (2, 3). Achieving these goals requires adopting innovative teaching–learning strategies aligned with the characteristics of the new generation of students (4, 5). Among modern approaches, gamification and microlearning have shown promise not only in enhancing motivation but also in managing the cognitive demands of learning (6).

Cognitive Load Theory (CLT) provides a crucial framework for designing effective learning environments by distinguishing three types of load on working memory: intrinsic (inherent to the material's complexity), extraneous (imposed by poor instructional design), and germane (devoted to schema construction) (7-9). Managing these cognitive demands is especially important for Generation Z learners, who are typically characterized by familiarity with digital technologies, reduced attention spans, and a preference for brief, focused content, making them particularly susceptible to cognitive overload (10, 11). Accordingly, instructional approaches should aim to minimize unnecessary cognitive strain while promoting deeper cognitive processing.

Microlearning addresses these needs by presenting information in concise, targeted segments. This approach directly manages intrinsic cognitive load by breaking down complex topics (like histological structures) into manageable segments, preventing working memory overload. Concurrently, it reduces extraneous cognitive load by presenting information in a clear, structured, and minimalist format, eliminating irrelevant processing (12-14). However, microlearning alone may not sufficiently engage learners.

Gamification, defined as the integration of game-like features into non-game environments, serves to increase learner engagement and motivation (15-18). More importantly, from a CLT perspective, well-designed gamification can reduce extraneous cognitive load by using clear goals, immediate feedback, and intuitive rules to streamline the learning process and minimize confusion. Furthermore, by increasing motivation and focused effort, it can potentially encourage learners to invest resources in germane cognitive load, thereby promoting deeper schema acquisition and transfer (16, 19). Empirical evidence highlights the positive impact of each of these strategies on both motivation and learning outcomes (20, 21)

Histology, with its abstract concepts, complex terminology, and reliance on detailed imagery, presents a high intrinsic cognitive load and is vulnerable to increased *extraneous load* through suboptimal instruction (22). An integrated gamification-based microlearning model offers a theoretically grounded solution: Microlearning manages the high intrinsic load of the content, while gamification reduces extraneous load and fosters germane processing. This synergy aims not merely to reduce load, but to optimize its distribution for better learning.

However, empirical evidence on the combined effect of these strategies on the specific dimensions of cognitive load in complex subjects like histology is scarce (23). Most studies measure overall load or motivation, neglecting the nuanced distinctions of CLT. Therefore, this quasi-experimental study aimed to investigate the effect of a gamification-based microlearning intervention on biology students' cognitive load in a histology course, with a specific focus on its differential impact on *extraneous* and *germane cognitive load*.

Methods

Study Design and Setting

This study employed a quasi-experimental design with a pretest–posttest control group framework. The study was carried out at Arak

University, Iran, from January to June 2024, within an undergraduate Histology course offered to biology students. The selection of a quasi-experimental approach was driven by practical and ethical challenges associated with random assignment in intact classroom settings, a common constraint in educational research contexts.

Participants and Sampling

The study population included all undergraduate biology students who were registered in the histology course at Arak University during the designated semester. Given the practical limitations associated with implementing the study within an ongoing course, a convenience sampling strategy was adopted by selecting a single intact class. The sample size (N=27) was therefore determined by the total number of students enrolled in that class. Although this approach is frequently utilized in quasi-experimental studies in educational settings, the lack of a prior power analysis is recognized as a limitation of the study.

Within this class, 27 students (all female, aged 19–22 years) were randomly allocated to either the experimental group (gamification-based microlearning, n=14) or the control group (traditional instruction, n=13). Randomization was carried out using a computer-generated random number sequence to promote equal group distribution and reduce selection bias.

A preliminary assessment indicated that none of the participants in either group had prior formal exposure to gamification or microlearning in educational contexts. Baseline comparability between the groups was evaluated before the intervention. An independent-samples t-test showed no statistically significant difference in cumulative Grade Point Average (GPA) between the experimental group (Mean=16.2, SD=1.1) and the control group (Mean=15.9, SD=1.3), ($t(25)=0.68$, $P=0.50$).

To minimize potential contamination bias, the following procedural controls were implemented: (1) all instructional materials and activities were delivered via separate, password-protected digital platforms; (2) students were instructed not to share login credentials or instructional content with peers from the other group; and (3) platform access logs were monitored by the primary investigator to ensure compliance.

Intervention/Procedures

The intervention was conducted over a 14-week semester, during which both groups covered the same core histology content and received equal instructional time (approximately 2 hours of practical sessions per week). The primary difference between the groups lay in the instructional approach. The experimental group learned through a custom-designed gamification-based microlearning platform, where content was delivered in short, focused modules enhanced with game elements such as points, badges, progress bars, and immediate feedback. In contrast, the control group received traditional instruction consisting of standard lectures, textbook readings, and static microscopic image reviews. To control for potential teacher-related effects, a single instructor taught both groups, ensuring that the core factual content remained identical. Additionally, the use of separate digital platforms, as described earlier, served as the main strategy to minimize cross-group learning transfer.

Experimental Group (Gamified Microlearning)

This group received instruction through a custom-designed gamified mobile application. Learners in the experimental group received the histology course content through a gamified educational application (Figure 1).

The application was designed with a “Journey into the City of Cells” theme and presented the content based on microlearning principles in the form of microlearning units (5–8-minute stages) (Figure 2), along with game mechanics such as missions, points, and badges (Figure 3).

This integrated framework was

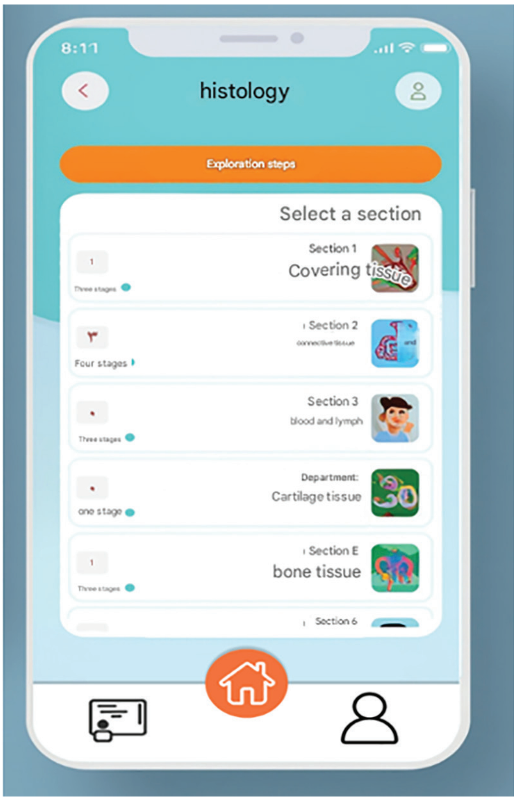

Figure 1: The general framework of gamification-based microlearning in teaching histology

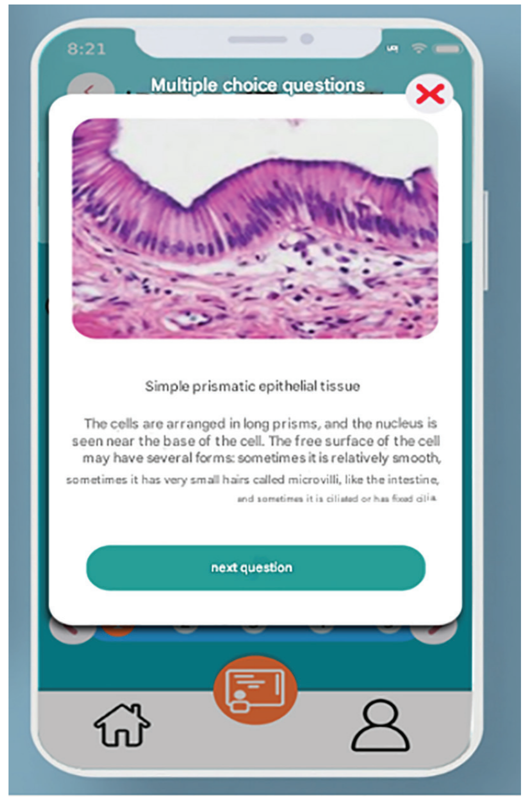

Figure 2: Microlearning at each stage, before entering the testing stage

conceptually based on CLT. The microlearning element was specifically structured to regulate the intrinsic cognitive load associated with complex histology material by dividing it into smaller, more manageable units. At the same time, its concise and targeted delivery was intended to reduce extraneous cognitive load.

The gamification component was introduced not only to enhance engagement but also to support the optimization of germane cognitive load. By boosting motivation and sustaining attention through game-based features, the intervention sought to encourage learners to allocate cognitive effort toward deeper processing and schema development.

The gamified features embedded within the application included:

• **Points:** Granted for completing levels and correctly answering quiz items.

• **Badges:** Earned upon reaching defined achievements (e.g., proficiency in a specific tissue type).

• **Leaderboard:** Presenting anonymized rankings to promote constructive competition.

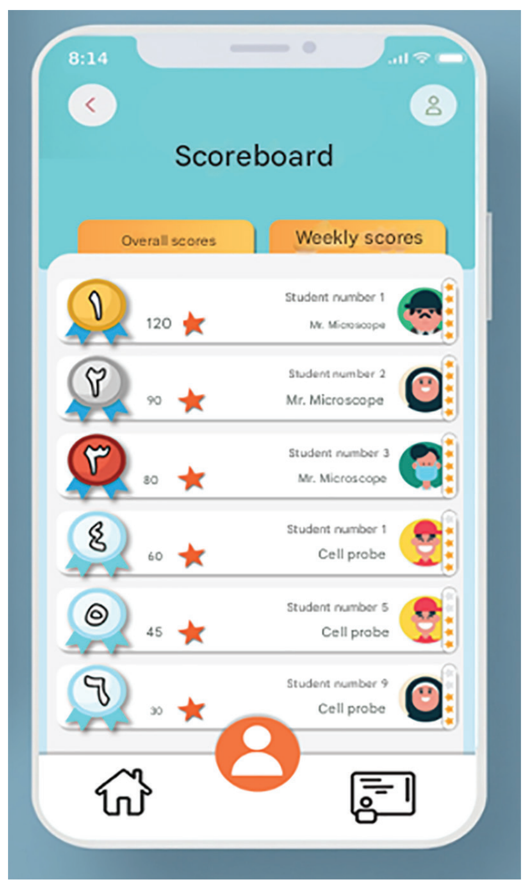

Figure 3: Scoreboard after learning and testing

• **Immediate Feedback:** Delivered after each quiz item, clarifying both correct and incorrect responses.

Learners were able to advance through the stages at their own pace and revisit materials whenever necessary.

Control Group (Conventional Instruction)

The control group (conventional instruction) received the same fundamental histological material through a traditional lecture-based format. To minimize potential instructor-related bias, both the control and experimental groups were instructed by the same educator. Teaching was conducted through face-to-face lectures supplemented with PowerPoint presentations and standard textbook images, reflecting the routine instructional approach without incorporating interactive or gamified components. Consequently, the only distinction between the two groups lay in the mode of instruction (gamified microlearning versus traditional lecture), while the instructor and core content remained consistent.

Tools/Instruments

The primary instrument used to measure the outcome variable was the Cognitive Load Questionnaire developed in 1992 by Paas (24). This tool consists of four items designed to evaluate the perceived difficulty of learning tasks and the amount of mental effort required. Responses are recorded using a 9-point Likert scale. The overall score is obtained by summing the responses to all items, resulting in a total score ranging from 4 to 40. The scale ranges from 1 (easy) to 9 (extremely difficult), with intermediate categories including very very low (2), very low (3), low (4), average (5), high (6), very high (7), and very very high (8). Higher total scores indicate greater cognitive load experienced by the respondent.

Validity and Reliability - In the study conducted by Ahadi and colleagues (25), the face and content validity of this questionnaire were confirmed by a panel of university faculty members. In the present study, content validity was further assessed at Arak University using the Content Validity Index (CVI), evaluated by five experts in instructional technology. The Item-level CVI (I-CVI) values ranged from 0.80 to 1.00, while the Scale-level CVI/Average (S-CVI/Ave) was 0.92, demonstrating strong content validity within this educational context. Additionally, previous research has established the construct validity of this instrument (26, 27). The internal consistency reliability of the questionnaire for the current sample was evaluated using Cronbach's alpha, yielding a coefficient of α=0.82, which reflects good reliability.

Data Collection

Data were gathered according to a predefined schedule:

1. Pre-test: At the start of the semester, prior to the implementation of the instructional intervention, both groups attended a standardized introductory session. This session introduced the basic concepts and learning objectives of the histology course. Immediately afterward, the Cognitive Load Questionnaire was administered to both groups to determine baseline cognitive load. This assessment reflected students' initial exposure to and processing of the core content under a uniform instructional condition.

2. Intervention Period: Over a 14-week period, instruction was delivered as previously outlined, with each group receiving its designated teaching approach (gamified microlearning or conventional lecture-based instruction).

3. Post-test: Immediately after the completion of the 14-week instructional intervention and all course topics, the Cognitive Load Questionnaire was administered again to both groups. This post-test evaluated the cognitive load associated with learning the full course content through each group's respective instructional method.

Data Analysis

All statistical analyses were conducted using IBM SPSS Statistics (Version 23).

Continuous variables were summarized using means and standard deviations (Mean±SD), and categorical variables were presented as frequencies and percentages. Initially, the primary outcome was intended to be analyzed using Analysis of Covariance (ANCOVA). However, the assumption of homogeneity of slopes (i.e., that the relationship between baseline cognitive load and post-test cognitive load is the same across groups, was not met. As this assumption was violated, ANCOVA results would not be interpretable under the model's requirements. Therefore, the primary outcome was analyzed using a change score approach. Specifically, a change score (Δ cognitive load) was computed for each participant by subtracting the pre-test score from the post-test score (Δ=post − pre). Negative values indicated a reduction in cognitive load. The normality of change scores was assessed using the Shapiro–Wilk test. As the distribution did not significantly deviate from normality (W=0.944, P=0.154), parametric testing was deemed appropriate. An independent-samples t-test was conducted to compare mean change scores between the experimental (gamification-based microlearning) and control (traditional instruction) groups. Effect size was calculated using Cohen's d with 95% confidence intervals. Statistical significance was set at α=0.05 (two-tailed).

Ethics - Ethical approval was obtained from the Ethics Committee of Islamic Azad University, Arak Branch, Iran. Participation was entirely voluntary, and all students provided informed consent prior to enrollment. Participants were assured of the confidentiality and anonymity of their data, and no personally identifiable information was collected or reported. Students were informed of their right to withdraw from the study at any stage without any academic penalty. Additionally, to ensure fairness, both groups received equivalent core instructional content, and no harm or disadvantage was imposed on any participant as a result of the intervention.

Results

All 27 participants from a single intact class were randomly allocated, following baseline assessment, to either the experimental group (gamification-based microlearning) or the control group (traditional instruction), and all were included in the final analysis (Figure 4). This study investigated the impact of gamification-based microlearning on the cognitive load of biology students. Baseline characteristics and descriptive statistics of the dependent variable across groups and testing phases are reported in Table 1.

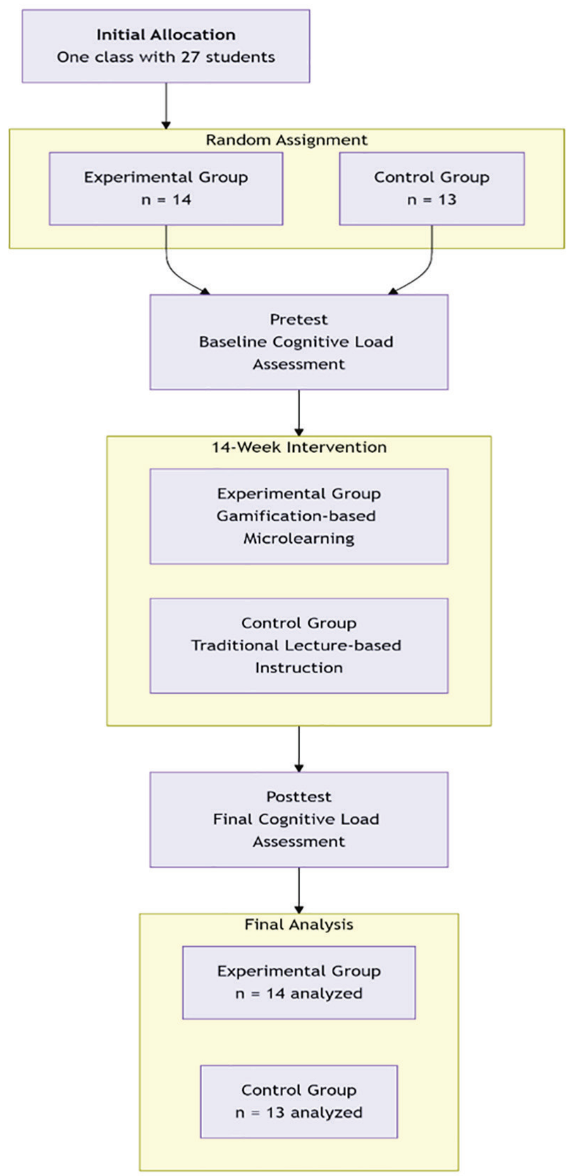

Figure 4: CONSORT flow diagram of participant allocation and progression through the study phases

Table 1: Baseline characteristics and descriptive statistics of cognitive load by group and test stage

Variable	Control Group (n=13)	Experimental Group (n=14)	P-value
Age (Years), Mean±SD	20.6±1.1	20.3±0.9	0.45
Gender, n (%)			
Female	13 (100%)	14 (100%)	-
Male	0 (0%)	0 (0%)	-
Prior GPA, Mean±SD	15.9±1.3	16.2±1.1	0.50

GPA: Grade Point Average; SD: Standard Deviation.

Table 2: pre- and post-test of groups and their differences and effect size

Variable	Control		Intervention		Between-Group (Post-test)	Hedges' g (Post-test)
	Pre (Mean±SD)	Post (Mean±SD)	Pre (Mean±SD)	Post (Mean±SD)		
Cognitive Load (Total score)	18.15±4.36	20.46±4.20	23.00±2.11	15.29±3.41	0.002	-1.32
Within Group	P=0.129		P<0.001			

SD: Standard Deviation.

Table 3: Comparison of cognitive load changes (post-pre) across groups

Variable	Control Group (n=13) Mean±SD	Experimental Group (n=14) Mean±SD	P-value	Effect Size Cohen's d (CI)
Change in Cognitive Load	2.31±5.11	-7.71±2.76	P<0.001	2.47 (1.44, 3.47)

SD: Standard Deviation; CI: Confidence Interval.

Table 1 presents the baseline characteristics of participants in the control and experimental groups. A total of 27 undergraduate biology students participated in the study (control: n=13; experimental: n=14). The mean age of participants did not differ significantly between groups (control: Mean=20.6, SD=1.1; experimental: Mean=20.3, SD=0.9; P=0.45). All participants in both groups were female. There was no statistically significant difference in prior academic performance, as measured by GPA (control: Mean=15.9, SD=1.3; experimental: Mean=16.2, SD=1.1; P=0.50). However, a significant difference was observed in baseline cognitive load scores. Table 2 presents the pre- and post-score of Cognitive Load (total score) in both groups and their differences and effect size.

The difference of post and pre mean of cognitive load score was not significant. The experimental group reported higher pre-test cognitive load (Mean=23.00, SD=2.11) compared to the control group (Mean=18.15, SD=4.36), and this difference was statistically significant (P=0.002).

Given the significant disparity in baseline cognitive load between the groups, the change in cognitive load (Post–Pre) was calculated and subsequently compared between the experimental and control groups (Table 3).

The analysis of change scores showed a notable difference between the groups (Table 2). Participants in the experimental group experienced a significant decrease in cognitive load (Mean=−7.71, SD=2.76), while those in the control group exhibited a slight increase over time (Mean=2.31, SD=5.11). An independent-samples t-test confirmed that this difference was statistically significant (P<0.001). The effect size was extremely large (Cohen's d=2.47), indicating a strong influence of the gamification-based microlearning intervention on lowering cognitive load. Additionally, the 95% confidence interval for Cohen's d (1.44 to 3.47) reinforces the stability and reliability of this effect. The negative mean change observed in the experimental group reflects a meaningful reduction in perceived cognitive load following the intervention.

Discussion

The results of this study indicated that gamification-based microlearning significantly decreased the relative cognitive load of biology students enrolled in the histology course, even though the experimental group initially demonstrated a higher baseline cognitive load in the pre-test. Specifically, the experimental group showed a substantial decrease, whereas the control group displayed a minimal and non-significant increase. The large effect size for the change score underscores the robust and sustained impact of the intervention. This result aligns with the positive perceptions of mobile learning reported by Mohammadi and colleagues (28), who found that learners in vocational and technical education experienced greater quality, depth, and flexibility including the opportunity to study anywhere and at any time when using mobile devices for learning.

Although our study used gamified microlearning on digital platforms rather than pure mobile learning, the shared principle of delivering content in small, accessible units that reduce cognitive barriers is evident across both approaches. This result can be interpreted from two perspectives. First, gamification enhances intrinsic motivation by creating a challenging yet rewarding learning environment, clearly highlighting the role of creativity in designing affective learning contexts (29). Second, microlearning by decomposing complex histology concepts into manageable, bite-sized units directly reduces intrinsic cognitive load and enables gradual mastery of the content (13, 30). Thus, presenting instruction in focused, modular units alleviates excessive demands on working memory, facilitating deeper conceptual understanding.

From a broader theoretical standpoint, our findings align with the growing body of evidence suggesting that instructional design grounded in CLT is particularly effective when it simultaneously addresses multiple types of cognitive load (7). In traditional histology education, the combination of high element interactivity (numerous tissue types, cellular structures, and functional correlations) and suboptimal presentation formats often imposes unnecessary extraneous load (31). The intervention in our study reduced this burden by presenting information in concise, gamified segments, allowing learners to focus their limited working memory capacity on schema construction rather than on deciphering poorly organized content.

The observed reduction in cognitive load among the experimental group is attributable to the synergistic integration of microlearning and gamification. Microlearning optimizes the structure of content delivery, while gamification optimizes the process and context of learning (32). This combined approach simultaneously mitigates extraneous load (e.g., anxiety, distraction) and redirects freed cognitive resources toward germane load—the effortful processing required to build and automate complex mental schemas (33). In this regard, the gamified microlearning environment likely encouraged students to allocate greater germane cognitive effort toward integrating new histology concepts with prior knowledge, thereby facilitating schema construction and consolidation (34).

A crucial point that merits further discussion is the role of immediate feedback in reducing cognitive load. In our gamified application, each microlearning stage was followed by instant explanatory feedback. According to Hattie and Timperley (35), feedback that clarifies misconceptions and confirms correct understanding reduces uncertainty, a major source of extraneous load. When learners receive immediate corrective feedback, they do not need to retain incorrect hypotheses in working memory, thereby freeing up resources for deeper processing. This mechanism likely contributed to the significant reduction in cognitive load observed exclusively in the experimental group.

In addition, Ahmadpour and colleagues (36) examined the effects of electronic versus traditional metalinguistic feedback on Iranian EFL learners' writing and reported that both approaches were similarly effective in enhancing accurate preposition use. Their findings indicate that the mode of feedback delivery, whether digital or conventional, is less critical than its immediacy and explanatory quality. This evidence supports the implementation of instant digital feedback within our gamified microlearning design. Overall, regardless of whether feedback is delivered electronically or through in-person interaction, its effectiveness in minimizing uncertainty and extraneous cognitive load appears comparable, provided that it is both timely and informative.

Furthermore, gamification elements such as badges, points, and leaderboards, may have influenced learners' emotional states, which are closely linked to cognitive load. Research has shown that positive emotions broaden the scope of attention and enhance cognitive flexibility, whereas anxiety narrows focus and consumes working memory capacity (37). By creating a low-pressure and engaging learning environment, our intervention likely mitigated test-related anxiety—a common challenge in histology education—thereby reducing the extraneous load associated with emotional regulation. This interpretation aligns with findings by Yıldız and Yaman (38), who demonstrated that gamified mathematics instruction decreased anxiety and improved learner performance.

Notably, gamification reduced extraneous cognitive load through several mechanisms. Immediate feedback after each stage allowed students to correct errors promptly and deepen their understanding (35).

The immersive "Journey to the City of Cells" framework, together with gamification components such as badges, points, and leaderboards, enhanced intrinsic motivation (39, 40). This, in turn, helped reduce affective barriers like test anxiety and disengagement, aligning with findings reported by Yildiz and Yaman (38). Moreover, the use of immediate rewards (41) and gradual advancement through levels (42) promoted sustained attention and self-regulation without the need for external cues.

An additional key factor is the congruence between the intervention and the learning characteristics of Generation Z students. All participants were aged 19–22 and thus represent digital natives who are accustomed to brief, interactive, and visually stimulating content (11). Conventional lecture-based methods often fail to maintain their attention, contributing to mind-wandering and increased extraneous cognitive load. In contrast, the gamified microlearning approach aligned with their preferences for rapid feedback, autonomy, and instant rewards, thereby decreasing the cognitive effort needed to remain engaged. This alignment between learner characteristics and the instructional environment may explain why the experimental group not only tolerated but also benefited from a relatively high initial cognitive load (pre-test mean=23.00), followed by a marked reduction.

The motivational and engaging design of gamification likely enhances sustained attention and reduces task-irrelevant processing, which may improve cognitive efficiency (43). This framework also clarifies why, despite receiving the same instructional content, the experimental group reported lower cognitive load and perceived complex material as more manageable.

Furthermore, a recent meta-analysis by Sailer and Homner (43) reported a small-to-moderate positive effect of gamification on cognitive learning outcomes, with stronger effects observed when paired with well-structured content—precisely the condition provided by microlearning in our study.

It is important to highlight that our findings challenge the common assumption that higher prior knowledge necessarily leads to lower cognitive load. Although the experimental group demonstrated a slightly higher, albeit non-significant, GPA (16.2 vs. 15.9), they unexpectedly exhibited a significantly greater cognitive load at pretest (23.00 vs. 18.15). This pattern suggests that students with stronger academic performance may initially experience increased cognitive load due to deeper engagement with the material, as they actively recognize its complexity and attempt to integrate new information with existing cognitive schemas (27). Notably, the substantial reduction in cognitive load following the intervention implies that gamified microlearning facilitated a shift from superficial to deeper processing, while maintaining cognitive demands within manageable limits of working memory. This aligns with the provision of well-structured content, a key feature of microlearning in the present study.

In summary, the purposeful combination of gamification and microlearning should be viewed not simply as a technological advancement, but as a pedagogically transformative strategy grounded in principles of cognitive psychology and learning sciences. By simultaneously lowering cognitive load through microlearning and enhancing intrinsic motivation via gamification, this approach fosters a supportive and engaging learning environment. As a result, students' focus shifts from anxiety about failure to the enjoyment of learning and skill development, ultimately contributing to a marked decrease in test anxiety.

From a practical standpoint, this framework offers three key considerations for educators and instructional designers. First, when designing courses with high intrinsic load (e.g., histology, anatomy, pharmacology), breaking content into micro-units (5–8 minutes) is not sufficient; these units must be embedded within a cohesive gamified narrative that provides clear goals and immediate feedback. Second, leaderboards should be used cautiously to avoid increasing extraneous load through social comparison anxiety; anonymous or self-referenced progress indicators may be more effective for anxious learners. Third, the integration should be theory-driven: every game element should serve a clear cognitive or motivational purpose, rather than being added arbitrarily.

Given the promising results, the gamified microlearning model shows strong potential as a novel instructional strategy for reducing cognitive load and enhancing the quality of cognitive learning in foundational biomedical disciplines. By combining effective teaching approaches with modern learners' preferences and purposeful technology integration, this model represents an important step toward creating more contemporary, engaging, and learner-centered higher education environments.

Limitations and Suggestions

This study has several limitations that should be considered when interpreting the findings. First, the research was conducted with a small, singlecenter sample drawn from one intact class. As the sample size was determined solely by the course enrollment and no prior power analysis was performed, the study had limited statistical power. Consequently, the results should be viewed as preliminary and interpreted with caution until replicated with larger and more diverse samples.

The quasiexperimental design, although appropriate for educational settings, lacked full individual randomization at the sampling stage, which may reduce generalizability. Additionally, the risk of contamination between groups within the same class, reliance on selfreport measures, and the shortterm assessment of undifferentiated cognitive load further constrain the interpretability of the results. Potential teacher effects and novelty effects associated with the gamified platform may also have influenced outcomes.

Significant baseline differences in cognitive load were also observed between the experimental and control groups. This imbalance, which arose from the quasi-experimental design, resulted in a violation of the homogeneity of slopes assumption required for ANCOVA.

Future research should employ larger, multicenter samples with sufficient statistical power and utilize individual randomization where feasible. Incorporating instruments that differentiate between types of cognitive load, using a combination of objective and selfreport measures, and accounting for instructorrelated and novelty variables would provide a more comprehensive understanding of the impact of gamificationbased microlearning on cognitive load.

Conclusion

The present study demonstrates that an integrated instructional strategy combining gamification and microlearning can effectively reduce cognitive load in complex and conceptually demanding subjects such as histology. The intervention was supported not only by statistically significant findings, but also by a large effect size, emphasizing the strength, consistency, and practical significance of its educational impact. Although the experimental group initially reported a significantly higher baseline cognitive load during the pre-test phase, cognitive load decreased markedly following implementation of the intervention. In contrast, the control group showed only a slight and non-significant increase over time.

The effectiveness of this instructional model appears to stem from its complementary cognitive mechanisms. Microlearning contributes to lowering intrinsic cognitive load by dividing complex material into smaller, manageable learning units, thereby facilitating gradual knowledge acquisition. Simultaneously, gamification helps reduce extraneous cognitive load by promoting engagement, decreasing learning-related anxiety, and encouraging self-regulated learning behaviors. Together, these approaches optimize the use of working memory resources and support deeper processing and schema construction associated with germane cognitive load.

These findings have important implications for educators and instructional designers in the medical and biological sciences. Gamified microlearning should be considered a scalable and evidence-informed instructional strategy that extends beyond improving learner motivation and engagement to directly addressing the persistent challenge of excessive cognitive load in foundational biomedical education. Future applications should maintain careful integration of both the structural features of microlearning and the motivational components of gamification to maximize cognitive, behavioral, and affective learning outcomes.

Abbreviations

ANCOVA: Analysis of Covariance
CLT: Cognitive Load Theory
CVI: Content Validity Index
GPA: Grade Point Average

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Authors' Contribution

MMN and SM were responsible for the study's conceptualization and methodology design. Data collection and curation, as well as formal analysis, were conducted by PM, SM, and MMN. The initial manuscript draft was prepared by PM, while MMN, SM, and HRM contributed to reviewing and revising the manuscript. Supervision and overall project administration were carried out by MMN, SM, and HRM. All authors reviewed and accept the final version of the manuscript.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Ethical Considerations

Approval for the study was granted by the Ethics Committee of Islamic Azad University, Arak Branch, Iran (IR.IAU.ARAK.REC.1404.003). Participation was voluntary, and informed consent was obtained from all students before inclusion. Confidentiality and anonymity were strictly maintained, with no collection or disclosure of personally identifiable information. Participants were also informed that they could withdraw from the study at any time without facing any academic consequences.

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Availability of Data and Materials

All data and materials used to support the findings of this study are available from the corresponding author on reasonable request.

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