EFFECTIVENESS OF CRIGLAM IN ENHANCING STUDENT ACHIEVEMENT AND INTRINSIC MOTIVATION

Keberkesanan CRIGLAM dalam Meningkatkan Pencapaian dan Motivasi Intrisik Pelajar

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ABSTRACT

Cellular respiration remains a challenging topic in biology education due to its abstract nature and low student engagement. While gamification and inquiry-based learning have been widely explored, limited research has examined their structured integration in improving both achievement and intrinsic motivation. This study investigates the effectiveness of the Cellular Respiration Challenge: A Gamified Inquiry-Based Learning Module (CRIGLAM). A quantitative pre-experimental design was employed involving 30 secondary school students. Student achievement was measured using pre- and post-tests, while intrinsic motivation was assessed using the Intrinsic Motivation Inventory (IMI). Data were analysed using paired-samples t-test and one-sample t-test. The findings revealed a significant improvement in achievement, with mean scores increasing from 52.67 (SD = 13.17) to 78.80 (SD = 9.97), $t(29) = 10.221$, $p < .001$, with a large effect size ($\eta^2 = 0.78$). Intrinsic motivation was also significantly higher than the theoretical mean ($M = 5.85$, $SD = 1.74$), $t(29) = 5.82$, $p < .001$. These findings indicate that CRIGLAM effectively enhances both conceptual understanding and intrinsic motivation. The study highlights the importance of integrating gamification with structured inquiry-based pedagogy to support meaningful biology learning.

Keywords: gamification, inquiry-based learning, cellular respiration, achievement, intrinsic motivation

ABSTRAK

Topik respirasi sel kekal mencabar dalam pendidikan biologi disebabkan sifatnya yang abstrak serta tahap penglibatan pelajar yang rendah. Walaupun gamifikasi dan pembelajaran berasaskan inkuiri telah banyak diterokai, kajian yang meneliti integrasi berstruktur kedua-dua pendekatan ini dalam meningkatkan pencapaian dan motivasi intrinsik masih terhad. Kajian ini bertujuan menilai keberkesanan Cellular Respiration Challenge: A Gamified Inquiry-Based Learning Module (CRIGLAM). Kajian ini menggunakan reka bentuk pra-eksperimen kuantitatif melibatkan 30 orang pelajar sekolah menengah. Pencapaian pelajar diukur melalui ujian pra dan pos, manakala motivasi intrinsik dinilai menggunakan Instrumen Intrinsic Motivation Inventory (IMI). Data dianalisis menggunakan ujian-t sampel berpasangan dan ujian-t satu sampel. Dapatan menunjukkan peningkatan signifikan dalam pencapaian, dengan min meningkat daripada 52.67 (SP = 13.17) kepada 78.80 (SP = 9.97), $t(29) = 10.221$, $p < .001$, dengan saiz kesan yang besar ($\eta^2 = 0.78$). Motivasi intrinsik juga didapati signifikan lebih tinggi berbanding min teoritikal ($M = 5.85$, $SP = 1.74$), $t(29) = 5.82$, $p < .001$. Dapatan ini menunjukkan bahawa CRIGLAM berkesan dalam meningkatkan kefahaman konsep dan motivasi intrinsik. Kajian ini menegaskan kepentingan integrasi gamifikasi dengan pedagogi inkuiri berstruktur dalam menyokong pembelajaran biologi yang bermakna.

Kata kunci: gamifikasi, pembelajaran berasaskan inkuiri, respirasi sel, pencapaian, motivasi intrinsik

INTRODUCTION

The teaching and learning of cellular respiration continue to present significant challenges in biology education due to the abstract, multilevel, and dynamic nature of the topic. Understanding cellular respiration requires students to integrate knowledge across molecular, cellular, and systemic levels while visualising processes that are not directly observable. As a result, students frequently develop misconceptions and fragmented understandings of energy transformation and metabolic pathways, limiting their ability to construct coherent scientific explanations (Opfermann et al., 2020). Recent research further indicates that traditional teacher-centred instructional approaches are often insufficient for promoting deep conceptual understanding in complex biological topics, highlighting the need for more student-centred and cognitively engaging pedagogical approaches (Southard et al., 2020).

In response to these challenges, gamification and Inquiry-Based Science Education (IBSE) have emerged as promising instructional approaches for enhancing student engagement and learning outcomes. Gamification involves the application of game-design elements, such as challenges, progression systems, and achievement mechanisms, within educational contexts to support learning. Recent meta-analytic evidence suggests that gamification can positively influence student engagement, motivation, and academic achievement when appropriately aligned with pedagogical objectives (Sailer & Homner, 2020; Zainuddin et al., 2020). Similarly, contemporary IBSE approaches encourage students to construct scientific knowledge actively through questioning, investigation, evidence-based reasoning, and problem-solving. Recent systematic evidence indicates that structured inquiry environments can enhance students' conceptual understanding, scientific reasoning, and engagement, particularly when appropriate scaffolding is integrated to support the inquiry process (Muhamad Dah et al., 2024).

Despite their potential benefits, both approaches present limitations when implemented independently. Research has shown that gamification may promote short-term engagement without necessarily supporting meaningful learning when game elements are not integrated with sound pedagogical principles (Clark et al., 2016; Zainuddin et al., 2020). Likewise, inquiry-based learning may impose high cognitive demands on students when adequate instructional support and scaffolding are not provided, particularly in conceptually demanding science topics (Muhamad Dah et al., 2024). These limitations suggest the need for instructional approaches that strategically integrate motivational and cognitive learning mechanisms within a coherent pedagogical framework.

Recent educational research has increasingly advocated the integration of gamification and inquiry-based learning to address both motivational and cognitive dimensions of learning. Studies indicate that combining motivational affordances with active learning strategies can enhance student engagement, persistence, and conceptual understanding more effectively than either approach alone (Clark et al., 2016; Lo & Hew, 2021). However, existing implementations often lack coherence, with gamification elements functioning as superficial enhancements rather than being systematically embedded within inquiry-based learning processes. Furthermore, relatively few studies have simultaneously examined both cognitive outcomes, such as achievement, and affective outcomes, such as intrinsic motivation, within a single instructional intervention.

Intrinsic motivation plays a critical role in meaningful learning because it promotes persistence, deep engagement, and sustained academic performance. According to Self-Determination Theory, intrinsic motivation is strengthened when learning environments support students' needs for autonomy, competence, and relatedness (Ryan & Deci, 2020). Although gamification has frequently been associated with increased motivation, evidence suggests that its effects on intrinsic motivation depend largely on the extent to which game elements support these psychological needs rather than relying solely on external rewards (Howard et al., 2021; Zainuddin et al., 2020). Consequently, there remains a need for instructional designs that foster both meaningful engagement and sustained intrinsic motivation.

To address these gaps, the Cellular Respiration Challenge: A Gamified Inquiry-Based Learning Module (CRIGLAM) was developed by integrating gamification elements within a structured inquiry-based framework guided by the principles of Inquiry-Based Science Education. By aligning motivational mechanisms with inquiry processes, CRIGLAM aims to support both conceptual understanding and intrinsic motivation in learning cellular respiration. Therefore, this study seeks to examine the effectiveness of CRIGLAM in improving students' achievement and intrinsic motivation toward learning cellular respiration.

LITERATURE REVIEW

The learning of complex biological processes such as cellular respiration remains a persistent challenge due to its abstract, multilevel, and dynamic nature. Students are required to integrate knowledge across molecular, cellular, and systemic levels, often without direct visualisation, which leads to misconceptions and fragmented understanding (Opfermann et al., 2020; Southard et al., 2020). Studies highlight that students frequently fail to construct coherent mental models of biochemical processes, particularly when instruction relies on static representations and teacher-centred approaches (Stieff & DeSutter, 2021; Tibell & Rundgren, 2010). These challenges underscore the need for instructional approaches that simultaneously support conceptual understanding and sustained engagement.

Gamification has been increasingly adopted in education as a strategy to enhance engagement and motivation. Meta-analytic evidence indicates that gamification can significantly improve behavioural, emotional, and cognitive engagement when aligned with instructional design (Sailer & Homner, 2020; Clark et al., 2016). More recent studies further demonstrate that gamified learning environments can enhance academic performance by increasing time-on-task and promoting active participation (Su & Cheng, 2021; Zainuddin et al., 2020). However, the effectiveness of gamification is highly dependent on its design. Poorly implemented gamification, particularly those relying heavily on extrinsic rewards, may result in superficial engagement without meaningful learning gains (Toda et al., 2018; Zainuddin et al., 2020).). This suggests that gamification must be pedagogically grounded to produce sustained cognitive outcomes.

Inquiry-Based Science Education (IBSE) is widely recognised as a pedagogical approach that promotes active knowledge construction through questioning, investigation, evidence-based reasoning, and scientific explanation. Recent systematic reviews confirm that inquiry-based approaches support the development of scientific skills and conceptual understanding when appropriately implemented within structured instructional designs rather than fully unguided exploration (Urdanivia Alarcon et al., 2023; Ogegbo et al., 2024). Evidence from meta-analytic and synthesis studies indicates that inquiry learning contributes positively to student achievement and higher-order thinking, particularly when learning tasks are carefully sequenced and supported with scaffolding strategies that reduce cognitive overload during complex knowledge construction processes (Öztürk et al., 2022; Antonio & Prudente, 2023).

Contemporary research further refines this position by emphasising that the effectiveness of inquiry-based instruction is highly dependent on the level of guidance provided. Systematic evidence shows that structured and guided inquiry approaches tend to produce more consistent learning gains compared to minimally guided formats, particularly in science domains requiring integration across multiple representational levels (Dah et al., 2024). This has led to a growing consensus that optimal IBSE design involves a balance between learner autonomy and instructional support to ensure productive engagement and meaningful conceptual development.

In parallel, recent research has increasingly investigated the integration of gamification with inquiry-based learning as a strategy to enhance both motivational and cognitive dimensions of science education. Systematic findings suggest that combining motivational design elements with inquiry processes can improve engagement, persistence, and learning outcomes when gamification is embedded into the learning cycle rather than applied as superficial reward mechanisms (Hamari et al., 2021; Zainuddin et al., 2020). When both approaches are coherently integrated, learners are more likely to

sustain cognitive effort and participate in deeper scientific reasoning activities. Collectively, these findings indicate that effective learning environments are those in which motivational structures and inquiry-based pedagogy are intentionally aligned rather than treated as separate instructional layers.

Intrinsic motivation has been identified as a critical factor in sustaining meaningful learning. According to recent developments in self-determination theory, intrinsic motivation is strongly associated with autonomy, competence, and relatedness, which collectively influence persistence, deep learning, and academic achievement (Ryan & Deci, 2020; Howard et al., 2021). While gamification has been shown to enhance motivation, its impact on intrinsic motivation remains inconsistent, particularly when it emphasises external rewards over internal satisfaction (Sailer et al., 2017; Zainuddin et al., 2020). This reinforces the need for instructional designs that support intrinsic motivational processes rather than relying solely on extrinsic incentives.

Despite growing interest in gamified and inquiry-based learning, there remains limited empirical evidence on the effectiveness of their structured integration within specific and complex biology topics such as cellular respiration. Most studies either focus on general learning contexts or examine these approaches independently. Furthermore, few studies have simultaneously examined both cognitive outcomes (achievement) and affective outcomes (intrinsic motivation) within a single intervention. Addressing this gap is essential for developing instructional approaches that support both understanding and engagement in meaningful ways.

The CRIGLAM module addresses this need by integrating gamification elements within a structured inquiry-based framework. Unlike fragmented implementations, CRIGLAM aligns motivational and cognitive processes within a coherent instructional design, providing a systematic approach to learning cellular respiration. This study therefore contributes to the literature by examining the effectiveness of such integration in enhancing both student achievement and intrinsic motivation.

METHODOLOGY

Research Design

This study employed a quantitative pre-experimental design using a one-group pre-test and post-test approach to evaluate the effectiveness CRIGLAM in improving student achievement and intrinsic motivation. This design was selected because the primary purpose of the study was to examine the preliminary effectiveness of a newly developed instructional module before conducting a larger-scale experimental investigation. The design enabled the measurement of changes in learning outcomes within the same group of participants before and after exposure to the intervention. Furthermore, the intervention was implemented within an authentic classroom setting, allowing the module to be evaluated under normal instructional conditions. Although the absence of a control group limits the ability to establish causal relationships, the design is appropriate for exploratory studies aimed at evaluating educational innovations in real classroom contexts.

Participants

The participants consisted of 30 secondary school students enrolled in a biology course covering the topic of cellular respiration. Purposive sampling was employed to ensure that all participants had prior exposure to the topic and were able to meaningfully engage with the instructional intervention. Although the sample size was relatively small, it was considered sufficient for within-subject statistical analysis using paired-samples procedures. The focus of the study was to evaluate the effectiveness of CRIGLAM within a specific instructional context rather than to generalise findings to a broader population.

Research Instruments

Two primary instruments were utilised in this study: an achievement test and the Intrinsic Motivation Inventory (IMI).

The achievement test was developed to assess students' understanding of cellular respiration concepts. Content validity was established through expert review involving experienced Biology teachers and a Head of Science Department. The experts evaluated the relevance, clarity, and alignment of the items with the intended learning objectives and curriculum requirements. Revisions were subsequently made based on their recommendations.

To ensure reliability, the achievement test was administered under standardised conditions during both the pre-test and post-test phases. A structured scoring scheme was employed to maintain consistency in scoring, while the alignment between test items and instructional objectives further contributed to the dependability of the measurement.

Students' intrinsic motivation was measured using the Intrinsic Motivation Inventory (IMI), a widely recognised instrument grounded in Self-Determination Theory. The IMI assesses multiple dimensions of intrinsic motivation, including interest/enjoyment, perceived competence, effort/importance, pressure/tension, perceived choice, value/usefulness, and relatedness. The instrument has been extensively used in educational research and has consistently demonstrated strong validity and reliability across diverse learning contexts. Given its established psychometric properties, the IMI was considered appropriate for measuring students' motivational responses to the CRIGLAM intervention. The use of a well-established instrument reduced the need for re-validation within the present study.

Procedure

Data collection was conducted over a two-week period during the implementation of the CRIGLAM module. The intervention consisted of one instructional module comprising five lesson plans with a total instructional duration of approximately 8.5 hours. Prior to implementation, the classroom teacher was briefed on the module objectives, learning activities, and implementation procedures to ensure consistency in delivery.

At the beginning of the study, students completed a pre-test to determine their baseline level of achievement in cellular respiration. Following the pre-test, the classroom teacher implemented the CRIGLAM module during regular Biology lessons. The intervention consisted of five lesson plans delivered over a two-week period with a total instructional duration of approximately 8.5 hours. The lesson plans were designed based on the 5E Instructional Model (Engage, Explore, Explain, Elaborate, and Evaluate) to ensure the systematic integration of inquiry-based learning throughout the intervention. During the Engage phase, students were introduced to authentic biological scenarios and challenge-based tasks to stimulate curiosity and activate prior knowledge. The Explore phase involved guided investigations and collaborative activities that encouraged students to examine concepts related to cellular respiration. During the Explain phase, students constructed and communicated scientific explanations based on evidence gathered from the inquiry activities. The Elaborate phase required students to apply their understanding to increasingly complex tasks and gamified challenges, while the Evaluate phase provided opportunities for reflection, self-assessment, and demonstration of conceptual understanding. Gamification elements, including challenge completion, level, points and goal-oriented tasks, were embedded throughout the module to enhance engagement and motivation while maintaining alignment with inquiry-based learning principles. The intervention was conducted entirely by the classroom teacher rather than the researcher. This approach enhanced ecological validity by ensuring that teaching and learning occurred under authentic classroom conditions. Upon completion of the final lesson, students completed the post-test to measure achievement gains. Immediately after the post-test, students completed the Intrinsic Motivation Inventory (IMI) questionnaire to evaluate their motivational responses to the learning experience. All instruments were administered under standardised conditions to ensure consistency in data collection.

Threats to Validity

Several threats to internal validity were considered in this study. As the study employed a one-group pre-test and post-test design, testing effects may have occurred because participants completed similar assessments before and after the intervention. Maturation effects may also have influenced student performance due to natural development over time, while history effects may have arisen from external events occurring during the intervention period.

To minimise these threats, the intervention was conducted over a relatively short period of two weeks, reducing the likelihood of substantial maturation and history effects. In addition, all participants experienced the same instructional activities and assessment procedures under standardised conditions. Nevertheless, the absence of a control group remains a limitation of the design and restricts the extent to which causal inferences can be drawn. Therefore, the findings should be interpreted as preliminary evidence of the effectiveness of CRIGLAM, and future studies employing quasi-experimental or experimental designs are recommended to strengthen internal and external validity.

Data Analysis

Data were analysed using the Statistical Package for the Social Sciences (SPSS). A paired-samples t-test was conducted to determine whether significant differences existed between students' pre-test and post-test achievement scores following the intervention. To assess intrinsic motivation, a one-sample t-test was performed by comparing the mean IMI score against a theoretical mean value of 4, representing a neutral level of motivation on a seven-point Likert scale.

In addition to statistical significance, effect size was calculated using eta squared (η^2) to determine the magnitude of the intervention effect. Reporting effect size provides a more comprehensive interpretation of the findings by indicating the practical significance of the results and the educational value of the intervention.

DATA ANALYSIS

To determine the effectiveness of the CRIGLAM module, inferential statistical analyses were conducted to examine changes in student achievement and intrinsic motivation following the intervention.

Student Achievement

A paired-samples t-test was conducted to compare students' performance before and after the implementation of the CRIGLAM module. The results are in Table 1.

Table 1
Paired Samples t-Test

Comparison	Mean Difference	SD	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Pre–Post	26.133	14.004	2.557	20.904	31.363	10.221	29	

The results of the paired-samples t-test indicate a statistically significant difference between students' pre-test and post-test scores following the implementation of the CRIGLAM module. As shown in Table 1, the mean difference in scores was 26.133 (SD = 14.004), with a standard error of 2.557. The 95% confidence interval for the mean difference ranged from 20.904 to 31.363, indicating that the true mean improvement is consistently positive and not attributable to random variation.

The analysis revealed a highly significant result, $t(29) = 10.221$, $p < .001$, demonstrating that students' performance after the intervention was significantly higher than before. This finding provides strong evidence that the CRIGLAM module had a substantial impact on students' understanding of cellular respiration.

Importantly, the magnitude of the mean difference suggests not only statistical significance but also practical significance in learning outcomes. The relatively narrow confidence interval further indicates the consistency of improvement across participants, reinforcing the reliability of the observed effect.

Overall, these results confirm that the implementation of CRIGLAM led to meaningful gains in student achievement, supporting its effectiveness as an instructional intervention for enhancing conceptual understanding in complex biology topics.

The magnitude of the effect was further examined using eta squared (η^2), which yielded a value of 0.78, indicating a large effect size. This finding demonstrates that the CRIGLAM module had a strong and meaningful impact on students' understanding of cellular respiration.

Intrinsic Motivation

A one-sample t-test was conducted to determine whether students' intrinsic motivation after the intervention differed significantly from the theoretical mean value of 4, which represents a neutral level of motivation on a seven-point Likert scale.

Table 2
Mean Scores of Intrinsic Motivation Inventory

Construct	Mean	SD
a. Interest	5.471	0.978
b. Perceived Competence	4.644	0.874
c. Effort	5.120	0.665
d. tension	1.537	0.544
e. Perceived Choice	6.305	0.703
f. Value/Usefulness	6.497	0.611
g. Relatedness	6.421	0.698

The descriptive analysis of the Intrinsic Motivation Inventory (IMI) reveals that students demonstrated a generally high level of intrinsic motivation following the implementation of the CRIGLAM module. As shown in Table 6.5, most constructs recorded mean scores above 5.00, indicating a positive motivational response.

Specifically, the constructs of value/usefulness (M = 6.497, SD = 0.611), relatedness (M = 6.421, SD = 0.698), and perceived choice (M = 6.305, SD = 0.703) recorded the highest mean scores. These findings suggest that students perceived the learning activities as highly meaningful, relevant, and aligned with their learning needs. The high score for perceived choice further indicates that students experienced a sense of autonomy during the learning process, which is a critical factor in fostering intrinsic motivation.

In addition, the constructs of interest/enjoyment (M = 5.471, SD = 0.978) and effort/importance (M = 5.120, SD = 0.665) also demonstrated positive levels, indicating that students were actively engaged and willing to invest effort in completing the learning tasks. These findings suggest that the gamified and inquiry-based design of CRIGLAM successfully sustained students' attention and involvement throughout the learning process.

The construct of perceived competence (M = 4.644, SD = 0.874), although lower relative to other constructs, still reflects a moderately positive perception of students' ability to perform the tasks. This may indicate that while students were engaged and motivated, the cognitive demands of the topic required substantial effort, which is consistent with the complexity of cellular respiration.

Notably, the pressure/tension construct recorded a low mean score (M = 1.537, SD = 0.544), indicating that students did not experience significant stress or anxiety during the learning process. This is a desirable outcome, as lower levels of pressure are associated with more positive and self-directed learning experiences.

The results revealed that the mean intrinsic motivation score (M = 5.85, SD = 1.74) was significantly higher than the theoretical mean, $t(29) = 5.82$, $p < .001$. This indicates that students experienced a significantly positive level of intrinsic motivation following the use of the CRIGLAM module.

Overall, the findings suggest that the CRIGLAM module effectively supported key dimensions of intrinsic motivation, including autonomy, competence, and relatedness. The combination of high perceived value, strong engagement, and low pressure indicates that the learning environment was both motivating and conducive to meaningful learning. These results provide further support for the effectiveness of CRIGLAM in enhancing not only cognitive outcomes but also students' motivational engagement.

DISCUSSION

The findings of this study provide strong empirical evidence for the effectiveness of the CRIGLAM module in enhancing both student achievement and intrinsic motivation in learning cellular respiration. The substantial improvement in post-test scores, supported by a large effect size, indicates that the intervention produced not only statistically significant gains but also meaningful improvements in conceptual understanding. This finding aligns with recent meta-analytic evidence demonstrating that well-designed instructional interventions integrating active learning and digital engagement strategies can significantly enhance learning outcomes in science education (Sailer & Homner, 2020; Clark et al., 2016). In particular, the magnitude of improvement observed in this study suggests that the effectiveness of CRIGLAM extends beyond surface-level engagement to support deeper cognitive processing.

The improvement in student achievement can be attributed to the structured integration of inquiry-based learning within the CRIGLAM module. Inquiry-based approaches have been consistently shown to promote conceptual understanding by engaging learners in active knowledge construction and problem-solving processes (Pedaste et al., 2020; Lazonder & Harmsen, 2016). More recent studies further indicate that guided inquiry, when supported by appropriate scaffolding, enhances students' ability to connect abstract scientific concepts to meaningful representations (Stieff & DeSutter, 2021; Southard et al., 2020). The design of CRIGLAM appears to operationalise these principles effectively by providing structured learning sequences that balance exploration with guidance, thereby reducing cognitive overload while maintaining active engagement.

In addition to cognitive gains, the findings also revealed a significant increase in intrinsic motivation, indicating that CRIGLAM supports key psychological processes associated with meaningful learning. According to recent developments in self-determination theory, intrinsic motivation is closely linked to the satisfaction of autonomy, competence, and relatedness, which collectively influence engagement and academic performance (Ryan & Deci, 2020; Howard et al., 2021). The gamified elements embedded within CRIGLAM, such as progressive challenges and feedback mechanisms, likely enhanced students' perceived competence, while the inquiry-based structure supported autonomy through active participation in learning. This integrated design aligns with recent findings that effective gamification enhances intrinsic motivation when it supports psychological needs rather than relying solely on extrinsic rewards (Sailer et al., 2017; Su & Cheng, 2021).

Importantly, the findings of this study extend current literature by demonstrating that the effectiveness of gamification is contingent upon its pedagogical integration rather than its mere presence. While previous studies have reported mixed outcomes regarding the impact of gamification on learning, recent reviews highlight that poorly designed gamification may increase engagement without improving learning outcomes (Clark et al., 2016; Zainuddin et al., 2020). In contrast, CRIGLAM integrates gamification within a structured inquiry-based framework, ensuring that engagement is aligned with cognitive processes. This supports the argument that the effectiveness of gamification depends on its alignment with instructional design and learning objectives, rather than its use as an isolated strategy.

Furthermore, this study contributes to the growing body of research on integrated pedagogical approaches by providing empirical evidence within a specific and complex biology topic. While prior research has largely focused on general learning contexts, this study demonstrates that structured integration of gamification and inquiry-based learning can be particularly effective in addressing the challenges associated with abstract scientific content. This finding is consistent with recent studies emphasising the importance of domain-specific instructional design in enhancing learning outcomes (Stieff & DeSutter, 2021; Southard et al., 2020). By focusing on cellular respiration, this study provides a more nuanced understanding of how pedagogical integration can support both conceptual understanding and motivation in complex learning domains.

Despite these promising findings, several limitations should be acknowledged. The use of a one-group pre-experimental design limits the ability to establish causal relationships, as the absence of a control group introduces potential confounding variables. Additionally, the relatively small sample size restricts the generalisability of the findings. However, recent methodological discussions suggest that strong effect sizes in within-subject designs can provide meaningful preliminary evidence of intervention effectiveness (Clark et al., 2016; Howard et al., 2021). Therefore, while the findings should be interpreted with caution, they provide a strong foundation for future research employing more rigorous experimental designs.

Overall, the findings suggest that CRIGLAM represents a viable and effective instructional approach for enhancing both achievement and intrinsic motivation in biology education. The integration of gamification with structured inquiry-based learning offers a promising direction for addressing persistent challenges in teaching complex scientific concepts. More importantly, this study reinforces the need for pedagogically grounded instructional design, where engagement strategies are systematically aligned with cognitive and motivational processes to support meaningful learning outcomes.

CONCLUSION

This study provides empirical evidence on the effectiveness of the Cellular Respiration Challenge: A Gamified Inquiry-Based Learning Module (CRIGLAM) in enhancing both student achievement and intrinsic motivation in learning cellular respiration. The findings demonstrate that a structured integration of gamification and inquiry-based pedagogy can produce meaningful improvements in both cognitive and affective learning outcomes, particularly in complex and abstract biology topics.

The significant gains in achievement, supported by a large effect size, indicate that CRIGLAM facilitates deeper conceptual understanding rather than superficial learning. At the same time, the observed increase in intrinsic motivation highlights the importance of designing learning experiences that support autonomy, competence, and meaningful engagement. These findings reinforce the need to move beyond isolated instructional strategies towards coherent pedagogical designs that align engagement mechanisms with cognitive processes.

This study contributes to the growing body of research on gamified learning by demonstrating that the effectiveness of gamification is highly dependent on its integration within a structured pedagogical framework. The CRIGLAM module offers a practical model for educators seeking to implement engaging and conceptually meaningful learning experiences in biology classrooms.

However, the study is limited by its pre-experimental design and small sample size, which restrict the generalisability of the findings. Future research should employ more rigorous experimental designs and larger samples to further validate the effectiveness of CRIGLAM across different contexts and student populations.

In conclusion, the integration of gamification with structured inquiry-based learning represents a promising instructional approach for addressing persistent challenges in science education. CRIGLAM provides a scalable and pedagogically grounded model that supports both understanding and motivation, offering valuable implications for teaching and learning in biology.

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