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Development and Preliminary Evaluation of Cell Division Escape Kit for Teaching Cell Division to Form Four Biology Students

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Abstract

One of the major challenges in biology education is students' difficulty in understanding the abstract concepts of cell division. Many struggles with the sequential stages of mitosis and meiosis, as well as the molecular basis of processes such as crossing over. Traditional lecture methods are often ineffective in addressing these complexities, resulting in persistent misconceptions. Furthermore, standardized assessments typically emphasize lower-order questions, which do not adequately capture students' conceptual understanding of cell division. Therefore, this study aimed to develop and evaluate the Cell Division Escape kit, a game-based learning aid for Form Four Biology, with a focus on its validity and usability. A developmental research design guided by the ADDIE instructional model was employed. The instruments used were an expert validation form and a usability questionnaire. Two Biology experts, one from Universiti Pendidikan Sultan Idris and another from Pahang Matriculation College, evaluated the kit for content validity. The usability of the kit was tested with 32 Form Four Biology students, while a pilot study involving 12 students was conducted to establish reliability. Data were analyzed using the Content Validity Index (CVI), Cronbach's alpha, and descriptive statistics via SPSS Version 29.0. The results showed that the Cell Division Escape kit achieved a CVI value of 1.00, an overall Cronbach's alpha of 0.97, and a high usability level with a mean score of 3.78. These findings demonstrate that the kit possesses high validity, strong reliability, and satisfactory usability. In conclusion, the kit provides a practical and engaging teaching tool to enhance students' understanding of cell division.

Keywords: Biology Education, Game-Based Learning, Cell Division, Teaching Aid, Cell Division ESCAPE Kit

Introduction

Biology is a core discipline that underpins scientific and technological advancement, yet it is often regarded as a difficult subject due to its abstract concepts and heavy reliance on

memorization (Çimer, 2012). One of the most challenging areas is cell division, where students struggle to grasp the sequential processes of mitosis and meiosis. Misconceptions such as believing DNA replication occurs during prophase or that chromosome numbers change incorrectly during mitosis remain widespread. These difficulties are compounded by dense scientific terminology and reliance on static instructional materials, which hinder meaningful understanding (Salleh et al., 2021; Musa Dikmenli, 2010; Rodríguez Gil et al., 2018).

Conventional lecture-based approaches are insufficient to resolve these challenges, as teacher-centered methods limit active participation and often result in shallow comprehension (Awaah et al., 2023; Yu and Sumayao, 2022; Sasithep Pitiporntapin and Suradet Sritha, 2025). In contrast, modern pedagogical frameworks such as 21st Century Learning (PAK-21) emphasize collaboration, inquiry, and problem-solving to promote deeper engagement (Wong and Kamisah Osman, 2018). Various innovations, including the 5E learning cycle (Arslan et al., 2015), cooperative methods such as Jigsaw (Sezek, 2012), instructional comics (Yu and Sumayao, 2022, and digital scaffolds (Esquivel-Martín et al., 2024), have shown potential in improving student understanding of cell division. However, many of these approaches are either confined to specific subtopics or rely heavily on digital resources that may not be accessible in all classroom contexts.

Game-based learning (GBL) has gained attention as a promising strategy for enhancing motivation, engagement, and knowledge retention. Research shows that GBL not only improves conceptual understanding but also supports higher-order skills such as critical thinking, collaboration, and creativity (Nestor Jr Lasala, 2023; Nestor Jr Lasala, 2022; Sadler et al., 2013; López-Fernández et al., 2024; Panzoli et al., 2017; Risya Pramana Situmorang et al., 2024). In biology education, game-based tools such as Cell Cycle Learn have demonstrated effectiveness in teaching complex cellular processes (Cruz et al., 2024). Despite these benefits, there is a lack of comprehensive, curriculum-aligned physical teaching aids that cover the full scope of cell division at the secondary school level. To address this gap, the present study introduces the Cell Division Escape kit, a game-based learning aid designed for Form Four Biology students in Malaysia. The study aimed (i) to develop the kit as a curriculum-aligned teaching tool for the topic of cell division and (ii) to evaluate students' perceptions of its usability in enhancing their understanding. By providing an engaging, hands-on alternative to traditional instruction, this study seeks to contribute a practical solution to one of the most conceptually important areas of biology.

Literature Review

The understanding of cell division, encompassing mitosis and meiosis, is a cornerstone of biological education. Yet, this topic has long been identified as a persistent source of difficulty and misconception for both secondary and undergraduate students. Usa Nakthong et al. (2025) documented how students frequently struggled to distinguish between mitosis and meiosis, particularly when predicting chromosome numbers in daughter cells. This confusion over haploid and diploid states represents a major conceptual hurdle. Similarly, Cossa et al. (2008) found that the abstract nature of chromosome structure, duplication, and segregation hindered comprehension. Many students treated these processes as isolated events to memorize rather than as a continuous, purposeful sequence.

Cisterna et al. (2013) further observed that students often conflated the terms genes, chromosomes, and DNA, revealing a failure to integrate new content with prior knowledge. Later research confirmed these misconceptions, especially in relation to meiosis. Musa Dikmenli (2010) reported that many students believed DNA replication occurred during prophase I rather than the preceding S phase of interphase. Others were unclear about when chromosome number is reduced, often assuming it remains unchanged during meiosis I and is halved only during meiosis II. Further misunderstandings included the assumption that chromosomes always contain two chromatids, as well as confusion between mitotic and meiotic processes. For instance, some students believed the chromosome number doubles in prophase of mitosis and halves in anaphase (Musa Dikmenli, 2010; Taklin Lukša et al., 2016). Importantly, many also failed to grasp the central purpose of meiosis: the production of haploid gametes for sexual reproduction and the promotion of genetic diversity. Taklin Lukša et al. (2016) noted gaps in understanding the reduction of chromosome number, while L. Kate Wright et al. (2021) emphasized that the role of homologous pairing and crossing over in ensuring genetic variation and accurate segregation is frequently overlooked.

Recognition of these persistent challenges led to a shift away from passive lecture-based teaching toward active, student-centered strategies. Traditional chalk-and-talk instruction was insufficient to make the abstract processes of cell division tangible (Awaah et al., 2023). Constructivist approaches soon gained prominence. For example, Sasithep Pitiporntapin and Suradet Sritha (2025) demonstrated the effectiveness of clay animation and stop-motion, where physically modeling stages of division improved both understanding and attitudes. At the same time, digital tools emerged as powerful resources. Multimedia that combined detailed images, explanatory text, and animations provided essential support for visualizing microscopic processes. Esquivel-Martín et al. (2024) argued that such tools develop the multimodal literacy needed to master complex biological concepts. This progression from passive reception to active creation and visualization marked a significant pedagogical advance.

More recently, game-based learning (GBL) has become one of the most promising approaches. Unlike earlier innovations that focused on clarifying content, GBL enhances the learning process itself, making it more engaging and motivating. Early advocates such as Moschini (2008) highlighted its potential, and subsequent studies have confirmed its effectiveness. In secondary biology, serious educational games have improved student performance compared with traditional instruction (Hodges et al., 2021). Longitudinal research shows that gamification promotes higher knowledge retention (Putz et al., 2020), while quasi-experimental studies confirm better academic performance and motivation in gamified courses (Yang and Kang, 2020; Jaramillo-Mediavilla et al., 2025). The accessibility of digital platforms has further enabled adoption. For instance, Quizizz improved test scores for the majority of students in one study (Noor et al., 2022). Meta-analyses and large-scale studies consistently affirm the positive effects of GBL across diverse contexts (Misra et al., 2022; Yu et al., 2021).

Although approaches such as clay animation (Sasithep Pitiporntapin & Suradet Sritha, 2025) and digital platforms (Noor et al., 2022) have proven effective, there remains a need for tools that are both highly engaging and tailored to the specific conceptual challenges of cell division. The *Cell Division Escape* Kit addresses this gap by synthesizing lessons from prior

research. It provides a hands-on, constructivist learning experience; employs narrative and puzzle-based activities to make abstract ideas more concrete; and leverages the motivational power of gamification. This study therefore advances the field by developing and evaluating a targeted GBL intervention designed to overcome well-documented misconceptions about cell division, representing the next step in this evolving pedagogical landscape.

Materials and Methodology

Study Design

This study employed a design and development research approach to produce a learning aid material for the biology topic of cell division. The development process was guided by the ADDIE instructional design model, which consists of five phases: analysis, design, development, implementation, and evaluation. Each phase was systematically carried out to ensure that the Cell Division Escape kit aligned with curricular standards and pedagogical objectives. During the analysis phase, data were gathered from Biology teachers using questionnaires to identify challenging topics in the Form Four Biology curriculum. Findings revealed that cell division was among the most difficult topics for students to master, consistent with earlier studies reporting widespread misconceptions. The design of the kit was underpinned by two theoretical frameworks: Cognitive Learning Theory, which emphasizes reinforcement through repetition and memory recall, and Constructivist Learning Theory, which highlights active knowledge construction through collaboration. The Cell Division Escape kit (Figure 1) was conceptualized as a physical game-based tool modelled after an “Escape Room,” incorporating collaborative gameplay and scaffolded tasks. Activities included diagram labelling, drawing, arranging stages of mitosis and meiosis, and decoding Morse codes, supported by colourful visuals and QR codes for video instructions. The development phase involved constructing a prototype consisting of question sets, answer keys, diagram labels, keywords, scoreboards, and supporting tools. Peer and expert reviews were conducted, and revisions were made accordingly.

Population, Samples, and Sampling Techniques

The study sample consisted of Form Four Biology students from two secondary schools in Malaysia. For the pilot study, 12 students were selected to establish the reliability of the usability questionnaire and to obtain preliminary feedback on the kit. In the main study, 32 Form Four students participated in the usability evaluation. Expert validation was carried out by two Biology lecturers: one from Universiti Pendidikan Sultan Idris and one from Pahang Matriculation College, both with more than five years of experience in the field. A purposive sampling technique was applied for expert validation, while convenience sampling was used for student participants.

Figure 1 Content Structural Design of the Cell Division Escape Kit as Teaching Aid

Research Instruments

Two instruments were employed in this study: the expert validation form and the usability questionnaire. The expert validation form was used to assess the face and content validity of the kit and the questionnaire items. The usability questionnaire, developed using a four-point Likert scale, comprised 26 items divided into three constructs: importance, design, and usability. Students responded on a scale from 1 (strongly disagree) to 4 (strongly agree).

Data Analysis

Data analysis focused on three aspects: validity, reliability, and usability. Content validity was measured using the Content Validity Index (CVI) at both the item level (I-CVI) and scale level (S-CVI), as recommended by (Polit and Beck, 2006). Reliability of the usability questionnaire was tested using Cronbach's alpha through a pilot study with 12 students. The threshold for reliability where values above 0.90 are considered excellent. Usability data from the main study were analyzed descriptively using SPSS Version 29.0, calculating mean scores and standard deviations.

Study Procedure

The study procedures were carried out in five phases according to the ADDIE model. In the analysis phase, data from teachers and past literature were used to determine students' difficulties in cell division. In the design phase, the structure, activities, and theoretical framework of the kit were established. During the development phase, the prototype was produced and refined through peer and expert reviews. The implementation phase involved a pilot study to test reliability and a main study with 32 students to evaluate usability. Finally, in the evaluation phase, descriptive analysis of questionnaire responses was conducted to determine the strengths, weaknesses, and overall usability of the Cell Division Escape kit. Table 1 summarizes the key activities and outcomes for each ADDIE phase.

Table 1
Summary of ADDIE Phases in the Development of Cell Division Escape kit

Phase	Key Activities	Outcomes
Analysis	• Collected input from Biology teachers using questionnaires. • Reviewed literature on misconceptions in cell division.	• Identified cell division as one of the most difficult topics. • Confirmed need for a practical and engaging learning aid.
Design	• Planned activities aligned with curriculum learning objectives. • Applied Cognitive Theory (reinforcement through repetition) and Constructivist Theory (collaborative learning). • Integrated Escape Room elements (puzzles, diagrams, labeling, Morse codes, QR video guides).	• Prototype blueprint created. • Kit designed to motivate students through collaborative, game-based tasks.
Development	• Constructed prototype with question sets, diagrams, answer keys, and supporting tools (e.g., magnifying glasses, scoreboards, marker pens). • Produced gameplay manual and QR code instructional video. • Conducted peer and lecturer reviews for feedback.	• Validity confirmed by two Biology experts. • Pilot study conducted with Form Four students to test reliability.
Implementation	• Conducted pilot test with 12 Form Four students. • Revised kit based on expert and pilot feedback.	• Cronbach's alpha established for reliability.
Evaluation	• Conducted main study with 32 Form Four students using the kit and completing the usability questionnaire.	• Collected usability data from target population. • Identified strengths and weaknesses for future refinement.

Results and Discussion

The purpose of this study was to develop and evaluate the Cell Division Escape kit as a game-based learning aid material (LAM) for teaching cell division to Form Four Biology students. The findings demonstrate that the kit achieved high validity and reliability as an instructional tool and was perceived positively by students across the constructs of importance, design, and usability. Overall, these results suggest that the Cell Division Escape kit is a feasible and effective innovation for addressing challenges in teaching one of the most conceptually demanding areas of secondary school biology.

Validity and Reliability

The content validity of the Cell Division Escape kit was established through expert evaluation. As shown in Table 2, all Content Validity Index (CVI) measures such as Item-CVI (I-CVI), Scale-CVI/Average (S-CVI/Ave), and Scale-CVI/Universal Agreement (S-CVI/UA) achieved the maximum score of 1.00. This indicates excellent content validity, confirming that both experts judged every item to be clear, relevant, and aligned with the content standards for the topic of cell division. The experts further agreed that the kit and its associated instrument were well-constructed and comprehensive.

Table 2
Interpretation Of CVI Values for the Cell Division Escape Kit

CVI Index	Score	Interpretation
Item-CVI (I-CVI)	1.00	Excellent content validity
Scale-CVI/Average (S-CVI/Ave)	1.00	Excellent overall agreement across items
Scale-CVI/Universal Agreement (S-CVI/UA)	1.00	Excellent universal agreement between experts

Reliability analysis was conducted to determine the internal consistency of the questionnaire. As shown in Table 3, the Cell Division Escape kit instrument contained 26 items distributed across three constructs: importance, design, and usability. Cronbach's alpha values for each construct exceeded 0.90, with an overall coefficient of 0.97, indicating excellent reliability. These results confirm that the instrument consistently measured students' perceptions across all constructs. Together, the findings demonstrate that the Cell Division Escape kit and its associated instrument are both valid and reliable for evaluating students' perceptions of the learning aid.

Table 3
Reliability Analysis of the Cell Division Escape Kit Questionnaire

Construct	Cronbach's α	Interpretation
Important of Cell Division Escape kit	0.91	Excellent internal consistency
Design of Cell Division Escape kit	0.90	Excellent internal consistency
Usability of Cell Division Escape kit	0.95	Excellent internal consistency
Overall	0.97	Excellent internal consistency across all constructs

Preliminary Evaluation of Cell Division Escape Kit

Three constructs were evaluated in the usability perception of the Cell Division Escape Kit: importance, design, and usability, comprising a total of 26 questionnaire items. Table 4 presents the mean scores and standard deviations for each construct. Following Ong Sze Chong and Zamri Mahamod (2014), a mean score between 3.67 and 5.00 is considered high. For standard deviation, Ramlee (1999) notes that lower values indicate stronger consensus among respondents, whereas higher values reflect less agreement. Overall, the findings revealed a high mean score of 3.78, suggesting that respondents strongly agreed and generally had a positive perception of the Cell Division Escape kit as a learning aid for the topic of cell division. Each construct recorded mean values within the high range, confirming the kit's usability and acceptability.

Table 4
Evaluation of the Cell Division Escape Kit

Construct	Items	Mean	SD	Interpretation
Importance	The kit is related to the topic of cell division.	3.78	0.42	High agreement
	The content is accurate and relevant.	3.81	0.40	High agreement
	The kit helps deepen understanding of lesson content.	3.89	0.32	High agreement
	The kit can spark creativity.	3.85	0.36	High agreement
	The kit contains high moral values (no inappropriate content).	3.89	0.32	High agreement
Average (Importance)		3.84	0.36	High importance perception
Design	The design is aligned with learning objectives.	3.78	0.42	High agreement

Construct	Items	Mean	SD	Interpretation
	The design and layout are attractive and easy to use.	3.74	0.45	High agreement
	The design is neat and sturdy.	3.63	0.49	Moderate to high agreement
	The size is appropriate (medium-sized, portable).	3.74	0.45	High agreement
	The kit is easy to use.	3.81	0.40	High agreement
	The design is suitable for use during lessons.	3.89	0.32	High agreement
	Information provided is easy to understand.	3.81	0.40	High agreement
	Instructions provided via QR code and video.	3.67	0.48	High agreement
	Gameplay instructions are clear and engaging.	3.85	0.36	High agreement
	Text in gameplay instructions is clear and easy to read.	3.78	0.42	High agreement
	Visuals and audio in video are attractive and appropriate.	3.63	0.49	Moderate to high agreement
Average (Design)		3.76	0.43	High design perception
Usability	The kit achieves its learning objectives.	3.78	0.42	High agreement
	The kit facilitates teaching and learning.	3.78	0.42	High agreement
	The kit functions well.	3.74	0.45	High agreement
	The kit stimulates creativity and critical thinking.	3.78	0.42	High agreement
	The kit can be used for reinforcement during lessons.	3.78	0.42	High agreement
	The usability level of the kit is high.	3.63	0.49	Moderate to high agreement
	The kit helps save time during teaching and learning.	3.67	0.48	High agreement
	The kit nurtures curiosity.	3.85	0.36	High agreement
	The kit increases active participation in class activities.	3.78	0.42	High agreement
	The kit enhances understanding of cell division.	3.70	0.47	High agreement
Average (Usability)		3.75	0.44	High usability perception
Overall Average		3.78	0.41	High overall usability perception

Among the three constructs, *importance* recorded the highest mean score (M = 3.84, SD = 0.36). This indicates that students regarded the kit as highly relevant and beneficial for understanding cell division. This finding is significant given the persistent misconceptions students often hold about mitosis and meiosis, such as the belief that DNA replication occurs during prophase or that chromosome numbers double during mitotic division (Musa Dikmenli, 2010). By incorporating interactive tasks such as drawing, labeling, and decoding biological concepts, the Cell Division Escape kit provided opportunities for students to practice and consolidate their knowledge in an engaging way.

These results are consistent with previous studies showing that game-based tools enhance understanding of complex biological processes. For example, the Bio-Mission Ladder *Board* designed for meiosis also reported high usability scores, demonstrating that integrating play into learning supports deeper conceptual understanding (Ramlee, 1999). Similarly, research on teaching ecosystems to Grade 7 students showed that game-based activities not only improved academic performance but also increased student engagement and positive attitudes toward learning (Nestor Jr Lasala, 2022; Nestor Jr Lasala, 2023). The present study extends this evidence by demonstrating that such benefits apply beyond a single subtopic to the broader theme of cell division. Importantly, both high-performing and lower-performing students benefited from the kit, suggesting that it is an inclusive tool that provides equal learning opportunities. Moreover, studies indicate that game-based learning can foster long-term conceptual change and knowledge retention. For instance, a randomized controlled trial showed that game-based learning environments were effective in resolving misconceptions and promoting sustained understanding of molecular processes (Gauthier, 2024).

Following this, the design construct achieved a mean score of 3.76 (SD = 0.43), reflecting students' positive views of the kit's visual appeal, portability, and clarity of instructions. Students valued features such as the reward points system, colorful diagrams, and the integration of QR code video instructions, which collectively enhanced engagement and usability. The portability of the kit, being medium-sized and sturdy, ensured practicality for classroom use, while clear instructions supported smooth gameplay. These results align with earlier research on the design of educational kits. For example, studies on genetics kits have highlighted the importance of durable, user-friendly designs in sustaining students' interest over time (Wan Mohd Zaid & Mustafar, 2024). In the present study, the integration of both physical elements (such as diagrams, magnifying glasses, Morse code puzzles) and digital enhancements (QR codes for video guidance) represents a balanced approach that leverages multimodal resources to strengthen student learning. Teaching aids that incorporate elements such as color, sensory stimulation, and gamification can significantly improve learning outcomes by making concepts more concrete and engaging (Amarin & Al-Saleh, 2020; Liu et al., 2021). The slightly lower mean scores for some items, such as neatness and sturdiness (M = 3.63, SD = 0.49), suggest that refinement of physical components may further improve the user experience. Nonetheless, the consistently high scores across design elements indicate that the overall design effectively met pedagogical needs and motivated students to engage with the topic. As reported by Armbruster et al. (2009) active learning strategies, such as problem-based learning and student-centered pedagogies, have also been effective in increasing student engagement and satisfaction.

In addition to importance and design, the usability construct recorded a mean score of 3.75 (SD = 0.44), suggesting that students found the kit easy to use, functional, and effective in achieving learning objectives. The smooth flow of activities, guided by the ADDIE model, allowed students to remain actively engaged without interruptions. This finding aligns with the GameFlow model, which emphasizes that uninterrupted gameplay fosters deeper cognitive and emotional involvement. From a theoretical perspective, the results also confirm the applicability of both Cognitive Learning Theory and Constructivist Learning Theory. The scaffolded structure of the kit, beginning with basic recall tasks and progressing to higher-order problem-solving, supported memory reinforcement and knowledge transfer, as predicted by cognitive theory (Good and Brophy, 1990). At the same time, the collaborative nature of gameplay enabled students to actively construct understanding through discussion and peer interaction, consistent with constructivist approaches. These results are consistent with the findings of Che Kob et al. (2019), who reported that educational kits significantly improve student performance. For example, a study on the use of learning kits in mechanical design showed positive and significant differences in student achievement compared to conventional methods. Although overall usability scores were high, some concerns were identified. Students reported that certain tasks were overly complex, which posed challenges, particularly for those with weaker biology backgrounds. Time efficiency was also highlighted as a limitation, as multi-step tasks could lengthen gameplay beyond practical classroom constraints. Addressing these issues by adjusting the difficulty level and streamlining certain activities would further enhance the kit's efficiency and inclusiveness.

Despite these strengths, several limitations must be acknowledged to provide a balanced interpretation of the findings. The study involved a relatively small sample of 32 students, which restricts the generalizability of the results. Additionally, the cross-sectional design captured student perceptions at a single point in time, limiting conclusions about long-term retention and motivation. Finally, the study focused exclusively on students' perspectives, without incorporating teachers' views on classroom management, implementation challenges, and instructional effectiveness. However, the results of this study carry important implications for biology education. The Cell Division Escape kit can serve as a supplementary instructional tool that promotes active learning and reduces reliance on rote memorization. Teachers may use the kit during lessons, as a revision activity, or as an enrichment exercise to reinforce difficult concepts. Its portability and straightforward instructions make it suitable for diverse classroom contexts, including those with limited technological resources. By fostering collaboration, creativity, and problem-solving, the kit not only enhances content mastery but also supports the development of 21st-century learning skills.

Conclusion

The Cell Division Escape Kit successfully achieved the objectives of this study and addressed the research questions. The kit demonstrated high validity and reliability, along with a satisfactory level of usability perception among Form Four Biology students. Beyond these outcomes, the kit provides meaningful benefits for both teachers and students by fostering an engaging and enjoyable learning experience. Developed through a game-based learning approach, Cell Division Escape kit reduces stress in learning while encouraging sustained motivation and deeper mastery of cell division concepts.

Theoretically, this study extends the application of Cognitive Learning Theory and Constructivist Learning Theory in the context of game-based biology education. By combining scaffolded recall tasks with collaborative escape room activities, the kit operationalizes these frameworks in a novel way, illustrating how abstract biological processes can be transformed into tangible and interactive tasks. Contextually, the study introduces one of the first curriculum aligned, non-digital GBL tools for secondary school biology in Malaysia. This innovation is especially valuable in contexts with limited technological access, offering a portable, inclusive, and engaging alternative to traditional instruction.

Future research should address these gaps by (i) conducting pre- and post-tests to directly measure conceptual gains, (ii) implementing delayed retention tests to assess long-term impact, (iii) involving larger and more diverse student samples, and (iv) integrating teacher feedback to evaluate feasibility in varied classroom contexts. Comparative studies contrasting this kit with other innovative approaches, such as digital simulations or cooperative learning strategies, would also provide insights into its relative effectiveness

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